INCORPORATING CONTINUOUS RESPONSE AND REINFORCER DIMENSIONS INTO INTERVAL AND RATIO SCHEDULES

By

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This work is dedicated
to my Parents
Marian Williams and John H. Williams, Sr.,
with love.

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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In the operant laboratory, reinforcing stimuli are usually scheduled to follow discrete, repeatable responses according to contingencies based on the passage of time and/or the number of responses that have been emitted. Traditionally, measured dimensions of the responses and reinforcing stimuli are constrained to narrow limits of variability. Although this approach has been very fruitful, the evolution of the literature describing reinforcement schedule relations has progressed in a manner that does not fully represent the "natural" relations that schedules are intended to analogize. Previous papers have proposed a more general conceptualization of schedule relations that included continuous as well as discontinuous properties of responding and of reinforcing stimuli, and presented data for a series of contingencies under a continuous reinforcement schedule. The present research program is designed to extend this

conceptualization to fixed-interval and larger fixed-ratio contingencies using response and reinforcement duration as the continuous dimension. The formal and procedural properties of these new schedule contingencies are presented and a series of six experiments provide an initial demonstration and description of the behavior of human subjects under these schedules and under traditional schedules involving discrete responses and reinforcers. Performance under the traditional schedules was similar to that typically produced using animal and human subjects. Schedules based on response duration rather than count produced analogous performances, but with respect to response duration rather than rate. Fixed-interval schedules of correlated (or conjugate) reinforcement duration produced high rate or very long duration responding when response count and response duration respectively were related to reinforcement duration. The schedule incorporating response count and reinforcement duration produced highly variable responding in comparison with the schedule incorporating response duration and reinforcement duration which produced very stable responding. These results were in accordance with results from the previous study of these relations under continuous reinforcement.

PART 1
INTRODUCTION

The analysis of operant behavior has traditionally emphasized the property of repeatability and its corresponding dimensional quantities of count and frequency, both of which are discontinuous. This emphasis on repeatability and count is reflected in formal definitions that characterize reinforcement as an increase in the frequency of a response that has been followed by a reinforcer (e.g., Reynolds, 1968; Holland and Skinner, 1961; Whaley and Malott, 1971). Accordingly, in the laboratory study of reinforcement schedules, reinforcement is usually made contingent upon the occurrence of discrete, repeatable, almost instantaneous responses that have been completed when the reinforcer is delivered.

The advantage that has been gained by these standardized procedures has been substantial; they are a major reason for the advancement of operant/behavioral science. However, restricting the study of behavior to the study of relations between discrete responses and reinforcers does not seem to fit the range of relations that may be conceived of by even casual consideration of organisms in the natural environment. Exclusive study of discrete responses and reinforcers may limit the range (real or perceived) of our descriptions of behavior. Much of operant behavior in noncontrived or "natural" environments may instead not involve relations of response

and reinforcer properties of discrete and instantaneous events, but may involve relations of response and reinforcer properties that can assume a range of values along a number of dimensions. For example, a child's crying might be reinforced by parental attention based on the duration or intensity of crying, speeding might be reinforced by arriving at the destination sooner, or different amounts of aerobic exercise might result in different levels of the runner's high. Contingencies incorporating such continuously variable response and reinforcer dimensions are not well represented in the literature on reinforcement schedules.

More general discussions of operant behavior and reinforcement may be easily substituted for the language of discrete events. Catania (1984), for example, carefully avoids the use of specific response and reinforcer properties in his text book on learning. When defining reinforcement he writes, ". . . when responding produces reinforcers, responding increases." (p 62). Morse (1966) described the effect of reinforcement as follows: ". . . to strengthen and intensify certain aspects of ensuing behavior." (p 53). Shull (1979) refers to environmentally arranged relations, "between properties of behavior and properties of reinforcers." and the effect of reinforcement as, "enhancing the specific response properties on which it is contingent." (p 193). Such definitions provide a more general description of the process of reinforcement and operant behavior than those that specify an increase in the frequency of behavior, and are more in accordance with the nature of behavior in unrestricted environments.

Applied behavior analysis is concerned with behavior in non-contrived environments in which the response topographies are usually not restricted by physical attributes of the setting. Responses of concern to the applied behavior analyst are most often of diverse topographies and rarely have clean onsets and offsets (see Baer, 1986). The consequences that control these responses are often behaviors of other people, and are similarly variable and complex in topography. The relations responsible for the shaping and maintenance of such behavioral classes are often not based on the delivery of a discrete reinforcing event following clear onsets or offsets of discrete responses.

In part because of the difficulty in specifying and reliably recording discrete onsets and offsets of responses and consequences of applied significance, the description and manipulation of behavior in applied settings is increasingly based on dimensions of behavior other than count (Springer, Brown, & Duncan, 1981). Applied behavior analysis frequently uses measurement systems employing continuous interval recording, which essentially estimates the amount of time "filled" by the targeted behavior, reflecting (though not a direct measure of) duration.

The use of continuous measures in applied settings may be more than a matter of convenience. The nature of socially mediated behaviors in the natural environment may require contingencies based on response and reinforcer dimensions other than count or rate, especially continuous dimensions such as intensity and duration. Furthermore, the values of the particular dimensions of such relations

are not likely to remain constant from occasion to occasion but rather are likely to fluctuate in a dynamic and interrelated manner. This implies that the structure of the responses--their persistance and intensity--that make the behavior problematic may be due to relations that have few parallels in the basic analytic literature.

The degree to which exclusive reliance on single dimensions is helpful or detrimental to the advancement of general laws is not easily specified. It seems reasonable to explore empirically relations involving other response and reinforcer dimensions in order to directly document and extend the range of applicability to relations involving other than discrete responses and reinforcers.

Literature Review

Reinforcement of Response Properties

The bulk of analytical research on extending principles derived from the study of discrete responses to complex and continuous responses concerns response differentiation. Under response differentiation procedures, reinforcement is provided following responses possessing a specified value of a given dimension but not following responses possessing more or less than that value (e.g., Skinner, 1938). Various dimensions have been the subject of analysis in this way including force (Notterman & Mintz, 1965), duration (Skinner, 1938; Lane, 1964; Platt, Kuch, & Bitgood, 1973; Kuch, 1974; see Catania, 1970; Zeiler, 1986), location (Antonitis, 1951; Eckerman, Heinz, Stern, & Kowlowitz, 1980), lever displacement (Herrick, 1964; Herrick & Bromberger, 1965), response amplitude

(Millenson, Hurwitz, & Nixon, 1961), and IRT (e.g., Platt, 1984; Galbicka & Platt, 1986). See Galbicka (1988) for a history and analysis of differentiation procedures.

In general, response differentiation procedures have shown that the principles of reinforcement can be applied to responses defined along many dimensions and to units made up of patterns of responses (cf. Zeiler, 1986) . However, response differentiation procedures represent only a single class of relations and do not fully capture the intent of the present proposal because these procedures themselves employ relations of discrete events. The usual differentiation procedure is one in which emitted responses must exceed some amount of the specified dimension in order to qualify for reinforcement, and when a response qualifies it is incorporated into the contingency in terms of its dimensional quantity of count. These procedures are generically similar to traditional laboratory operant conditioning procedures (Platt, 1973; Galbicka, 1988) except that a separate criterion amount of a particular dimension is required for a response to be eligible for reinforcement, and that criterion is different than the threshold amount required for classification as a response for measurement purposes. Relations are then based on counts of responses defined by this criterion. The continuous nature of the response quantity is neither directly relevant to, nor a formal property of, the contingency. This is also true of other areas of research that extend the generality of reinforcement principles to other units, such as demonstrations of differential reinforcement of sequences and patterns of discrete responses (e.g., Findley, 1962; DeCasper &

Zeiler, 1977; Kelleher, 1966; Hawkes & Shimp, 1975), and second order schedules (Malagodi, DeWeese, & Johnston, 1973; see Marr, 1979 for a review).

Few studies have arranged contingencies based on quantities of continuous responses. Skinner (1938) reinforced wheel running by presenting food after a cumulative distance had been run, and Skinner and Morse (1958) reinforced wheel running on a fixed-interval schedule by presenting food for the first one-half turn after the expiration of the interval. Other responses used have included pushing a fixed bar (Notterman & Mintz, 1965), lever holding (Rider & Kametani, 1984; 1987), hand writing (Gonzalez & Waller, 1974), and vocalizations (Lane, 1964). The relations used in these studies were different from those in the usual response differentiation studies in that reinforcement was not based on the emission of an individual response having a predetermined quantity of a given dimension in an-all-or none fashion. Rather, reinforcement was delivered based on the emission of a criterion amount of a given dimension of ongoing responding. Moreover, the response was in progress at the time of reinforcement.

Reinforcer Dimensions

Dimensions of the reinforcing stimulus other than count have also been investigated, and the procedures parallel those used to study response dimensions. Typically, the effects of reinforcement magnitude are studied by providing a fixed amount of the reinforcing stimulus along a selected dimension, and varying that amount across phases, subjects, or experiments. Reinforcement dimensions are thus treated as discrete and static variables, and variation in dimensions

of the reinforcer is not a part of the relation. When varied in this manner, the amount of reinforcement has a remarkably limited effect on responding (Catania, 1963).

Much larger effects have been demonstrated by studies that vary reinforcement amount within sessions (Crespi, 1944; Logan, 1960; Davis & North, 1967; Harzem, Lowe, & Priddle-Higson, 1978; Catania, 1963). The effects of within-session variation in the amount of reinforcement depend on several factors such as whether the different amounts are signalled, as well as the pattern, direction, and duration of the change. The study of how variability in the amount of a reinforcing stimulus can affect performance goes one step beyond the treatment of reinforcers as instantaneous events, and seems to reflect natural conditions in which some aspect of reinforcement varies from presentation to presentation. However, such variation is not related to variation in responding and as such is not a direct component of the contingency.

In a related procedure, correlated reinforcement (Logan, 1960), the amount of reinforcement delivered on a given occasion varies as a function of the quantity of some dimension of responding such as speed of a runway response, (Logan, 1960), IRT (Hendry, 1962; Hendry & Van-Toller, 1964), or the number of responses (Gentry & Eskew, 1984; Buskist, Oliveira-Castro, & Bennett, 1988). Correlated reinforcement procedures have been shown to produce changes in the response property correlated with increased reinforcement; positive relations increase responding and negative relations reduce its level. However, the mechanisms for some of the effects are not always straight forward.

Logan (1960) demonstrated increased running speed over the length of the alley when speed was correlated with increased amounts of reinforcement. However, when larger rewards were correlated with slower running, the overall speed was reduced due to the animals stopping in front of the goal box and engaging in other behavior before entering. Furthermore, these relations do not inevitably control responding. Using pigeons, Gentry and Marr (1982) failed to obtain increased response rates when the number of responses emitted during the interval on a fixed-interval 5 min schedule was correlated with increased durations of grain presentations.

Conjugate reinforcement (Lindsley & Skinner, 1954; Lindsley, 1962) incorporates continuous responding and reinforcement into a relation directly. Typically, the rate of responding and the intensity of a consequent stimulus are correlated such that the higher the response rate, the more intense the consequent stimulus becomes, and conversely, intensity decreases as the response rate decreases. Other response and reinforcer dimensions have been related, such as the duration of infant vocalizations affecting properties of visual stimulation (Ramey, Heiger, & Klisz, 1972), activity and brightness of a projected movie (Switzky & Haywood, 1973), and a variety of others (See Rovee-Collier & Gekoski, 1979 for a review). Conjugate relations have proved powerful in demonstrating conditioning in subjects with whom conditioning was previously difficult to obtain, such as very young infants (Lipsitt, Peterson, & Delucia, 1966; Rovee-Collier & Capatides, 1979) and psychotic (Lindsley & Skinner, 1954; Lindsley, 1963), retarded (Switzky & Haywood, 1973), sleeping (Lindsley, 1957),

anesthetized (Lindsley, Hodika, & Etsten, 1961), and comatose (Lindsley & Conran, 1962) human subjects.

The rapidity and ease with which conditioning is obtained with such populations under conjugate reinforcement procedures has led some to speculate that conjugate reinforcement is the predominant schedule in nature (Lindsley, cited in Rovee-Collier & Gekoski, 1979). Although conjugate reinforcement shares some features with other correlated reinforcement procedures, varied reinforcement magnitude procedures, and response differentiation procedures, it also has some unique procedural attributes. No systematic analysis has been conducted to relate these procedures or evaluate components of conjugate reinforcement to describe the dimensions of its "naturalness."

The literature on behavior-reinforcer relations that involve properties of responding and reinforcers other than discrete occurrences is small and generally unsystematic, involving a variety of loosely related procedures. The systematic study of an expanded range of relations may help refine the description of known processes, thus increasing the generality and power of basic analysis for the explanation of behavior in noncontrived environments. One effect may be to better relate basic and applied conceptualizations. The path taken here is towards increased complexity, but with an aim to explore a system of procedures that allow the control and evaluation of this increased complexity. This is done by examining the procedures and performances when continuous response and reinforcer dimensions are added to the "system" of schedules research.

General Model

A general model for conceptualizing and integrating contingencies involving continuous and discontinuous dimensions has been described in detail by Williams and Johnston (in press,) and only the major points will be reviewed here.

Any operant contingency may be considered to be composed of at least three elements: the response or movement, the reinforcing consequent stimulus or environmental event, and the correspondence or relation between responses and consequent stimuli, i.e., the contingency (see Sidman, 1986 for a discussion of operant units). Each of the three elements has many properties, each of which is measurable across corresponding dimensions. Dimensional quantities can be either continuous or discontinuous. Continuous dimensions may assume any value, i.e., an infinite number of points along a continuous scale. In contrast, variability in discontinuous dimensional quantities is restricted to a finite number of discrete values. The bulk of the schedule literature manipulates dimensions of the correspondence or contingency and the participating dimensional quantities of responses and reinforcing stimuli are narrowly limited--most often to discontinuous quantities.

The specific arrangement of contingencies, starting with the way that the response and the consequent stimulus are defined, determine whether the continuous variability that is fundamental to continuous dimensions is actually a formal participant in the relation. Note that the critical distinction being made is whether the relation is

directly between properties of responding and changes in quantities of a specific dimension of reinforcement or whether fixed quantities of these dimensions are specified in the static definition of discrete events. For example, delivering reinforcement only when the time between the onset and the offset of a discrete response exceeds a certain value incorporates duration into the definition of the response event but not directly into the relation. The relation is between the discrete response event and reinforcement, and reinforcement may be contingent on the number of occurrences of responses of a certain duration, but reinforcement is not contingent on the duration of responding per se. The purpose of the general model and the present work is to explore contingencies that relate duration of responding directly to reinforcement. For example, a reinforcing stimulus may be delivered once a specified duration of responding has occurred regardless of the number of onsets and offsets of the behavior. Using the example of the runner's "high", the onset of the stimulation (the high) may be contingent on the emission of 30 min of aerobic exercise; a 20-minute bout does not produce the high. But if the runner discontinues and then re-initiates running, he or she does not have to emit a 30 min bout--only 10 min (provided the break is not too long). The relation of duration of exercise and onset of the high is based on cumulative duration of exercise, not simply the emission of a discrete exercise cycle (see Rider & Kametani, 1984; 1987 for discussion of such schedules).

The major goal of this model is to integrate systematically duration of responding and duration of the reinforcing stimulus with

traditional schedule procedures. Williams (1985) and Williams and Johnston (in press) demonstrated that fixed-ratio 1 (FR 1) schedule contingencies may be translated to incorporate response and consequent-stimulus duration rather than count and still maintain the formal properties of the schedule (the mathematical correspondence). An FR 1 relation specifies that one unit of the response dimension is required to produce one unit of consequent stimulation. The dimensions and their units were substituted interchangeably in the relation producing four schedule contingencies. Figure 1 presents the four relations obtainable using count and duration as examples of a single discontinuous and single continuous dimension. One of the four corresponded to the traditional FR 1 relation while the remaining three were new relations.

This model can be used to incorporate a continuous dimension into any simple schedule, yielding the four possible, generic relations shown in Figure 2. The contingencies may be described as follows:

1) One response produces one consequent-stimulus event (Count-Count relation).

2) One unit of response duration produces one consequent-stimulus event (Duration-Count relation).

3) One response produces one unit of consequent-stimulus duration Count-Duration relation).

4) One unit of response duration produces one unit of consequent-stimulus duration (Duration-Duration relation).

This model will be used to formulate the basic schedules used in the research program proposed here.

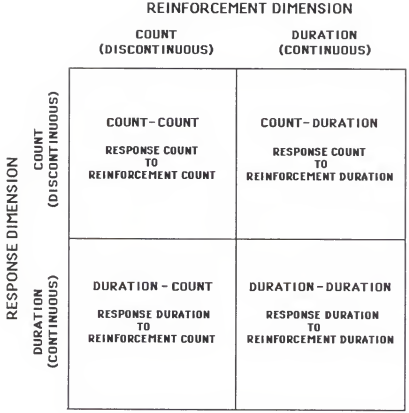


Figure 1. The four possible relations incorporating the dimensions of duration and count into a simple schedule.
Count-Count. One response produces one consequent-stimulus event.
Duration-Count. Accumulation of the unitary amount of response duration produces one consequent-stimulus event.
Count-Duration. One response produces one unit of consequent-stimulus duration.
Duration-Duration. Each unit of response duration produces an equal amount of consequent-stimulus duration.

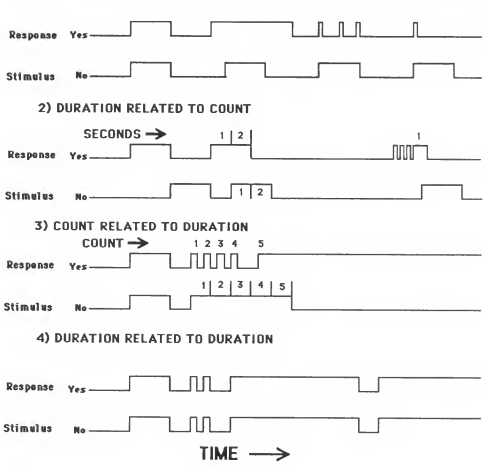


Figure 2. Schematic of the four possible relations incorporating count and/or duration under a continuous reinforcement schedule. The event (response or reinforcing stimulus) is occurring when the trace deflects up and is not occurring when the trace deflects down. The relative durations of events are indicated by horizontal distance.

The arbitrary designation of the unit of duration is necessary when a discontinuous dimension is related to a continuous dimension as in 2 and 3 above. In this case, duration was constrained to specific values in increments of the minimum unit value, one second. Fractional values cannot functionally occur because they have no corresponding value along the discontinuous dimension in the relation.

The present experiments are a direct extension of these conceptualizations to intermittent contingencies. The sections that follow are quite detailed and sometimes quite abstract, and a brief review of the procedures used in the previous work may help to clarify the discussion of the proposed contingencies. The following is a description of the apparatus and general procedures used by Williams (1985) and Williams and Johnston (in press).

Figure 3 presents a diagram of the apparatus used by Williams (1985) and Williams and Johnston (in press), and in the present study. The apparatus was a wooden cabinet housing a motorized filmstrip projector that back-projected onto a translucent screen mounted in the front panel of the cabinet. The manipulandum was a Plexiglas wheel located beneath the screen. Undergraduate student volunteers sat before this screen and turned the wheel which operated the projector through the control equipment. Lines of text were projected onto a screen contingent on responding. Each line was a part of a complete reading passage on which the subjects were tested and scored following each experimental session. Subjects were provided with feedback about their scores after each test to maintain reading behavior. Following shaping of the wheel turning response, subjects were exposed

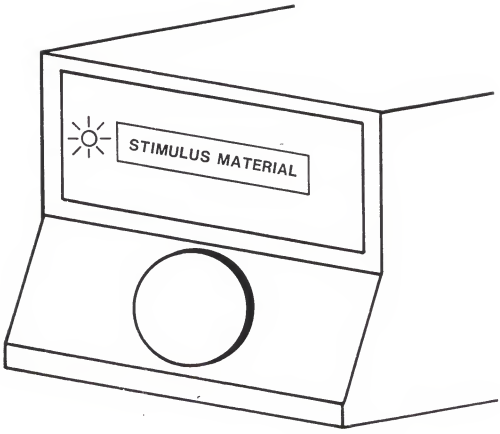


Figure 3. Drawing of the apparatus.

to one of four schedule contingencies presented in Figure 2. A response was counted when the wheel was turned the minimal amount for detection (see general methods section), that is, each time the subject started turning the wheel. Duration was the time between starting and stopping. There were no physical restrictions on the distance that the wheel could be rotated and it was possible for it to be turned continuously for any duration. The consequent stimulus could be presented in discrete controlled cycles or continuously for any duration.

The contingency that related response count to consequent-stimulus count produced relatively high rate and very short duration responding during conditioning, and bursts of responses and gradual cessation of responding during extinction. This performance was comparable to that under traditional preparations. Under the schedule relating response count to consequent-stimulus duration, response rates were higher and duration was also longer and more variable than under the traditional FR 1 schedule. Both schedules that incorporated duration as the response dimension produced low rate, very long duration responding. Of these two schedules, the contingency relating response duration to consequent-stimulus duration produced lower rates, longer durations, and a greater percentage of the session spent responding. Thus, the largest differences in responding were due to the type of response dimension incorporated, but variation in the consequent-stimulus dimension did have an influence by enhancing the main effect of the response dimension. The "irrelevant" response dimension, i.e., the one not formally related to reinforcement

(duration in the schedule incorporating count and vice versa), was generally enhanced under contingencies that related dissimilar response and consequent-stimulus dimensions (the count-duration and duration-count contingencies). The apparatus and general procedures developed for use in that study proved effective in producing performances that were sensitive to the scheduled contingencies and were employed in the present series of manipulations.

Although the previous manuscript presented data from FR 1 schedules only, the conceptualization was meant to be applicable to all operant schedules. The vast majority of traditional schedules as described by Ferster and Skinner (1957) are considered to be variations or combinations of simple ratio and interval schedules (Morse, 1966). Incorporating continuous response and consequent-stimulus dimensions into these fundamental simple schedules will extend the generality of the conceptualization to a major proportion of the schedule literature. Furthermore, partial reinforcement schedules, and especially interval schedules, are particularly useful for revealing the structure of responses and responding because responding is relatively unconstrained (Zeiler, 1979).

Research Strategy

The strategy that will be followed through the next few sections will be to discuss interval and then ratio schedules in a three-step process. First, the schedule will be discussed with the purpose of determining the features of the mathematical correspondence that are formally necessary for defining interval schedules and disentangling

these essential features from procedural details that have been determined by the traditional use of response and reinforcer count as the defined dimensional quantities of the schedule. Defining the generic features of ratio and interval schedules will allow the continuous dimension of duration to be incorporated while preserving the essential nature of the schedules.

The second step is to translate the terms used to describe interval and ratio schedules into a form that allows the formal incorporation of duration into the definition of the schedule contingency while preserving the formal features of the schedules and the continuous nature of duration. In practice, any term referring to count may be changed to specify a quantity of duration (or any other dimension).

The third step translates the formal properties derived in Step 2 into procedural details. Rationale for the procedures used are given, and the details will be described in the Methods sections. The position taken here is that the procedures for programming the various schedule contingencies should reflect two things. First, the formal properties or features of the mathematical correspondence should be represented in order to reproduce faithfully the generic schedules. Second, if a conflict arises between preserving traditional aspects and reflecting the nature of the continuous dimensional quantities, the latter will take precedence. Thus, selection of the programming procedures places priority on allowing natural variability in the dimensional quantities that are specified by the relation, rather than

constraining this variability to emulate the conditions of traditional procedures.

It is ultimately necessary to demonstrate generality at two levels--the formal properties of the schedules, and the properties of the performances generated by the schedules. Extending generality to the formal properties that define such schedules requires, at minimum, replicating the interval and ratio schedules at a single, arbitrary parameter value. Demonstration of representative performances, however, will require the demonstration of performances at additional ratio and interval values. These experiments are not intended as an exhaustive description of performance under these schedules, so parametric demonstrations will not go beyond those minimally required to demonstrate the applicability or generality of the proposed conceptualization to interval and ratio contingencies.

PART 2
FIXED-INTERVAL CONTINGENCIES

Introduction

Defining Features

An interval schedule is defined as the reinforcement of the first response following a specified period of time since some event--usually another reinforcement (Ferster and Skinner, 1957; Catania, 1973). Interval schedules specify two elements as conditional for reinforcement, the time (t) since the initiating event and the number of responses required for reinforcement (n) (Morse, 1966). In addition, the passage of time (t) is independent of responding, and responses during the "t" period have no programmed effect on reinforcement delivery. The traditional fixed-interval (FI) schedule may be characterized in terms of compound schedules as a tandem, fixed-time x, fixed-ratio 1 schedule (Tand FT x, FR 1) (Morse, 1966). This specification is useful because it accentuates the essential features of FI schedules.

Formal Translation

Translating these features of interval schedules into generic terms requires the preservation of the interval requirement, t, and the response requirement, n, which may be specified in units of any dimension appropriate to responding. Continuous response and consequent-stimulus dimensions may be incorporated into these

schedules in the same way as for the continuous reinforcement schedules described previously. Typically, interval schedules relate one unit of the response event--count, to one unit of the consequent stimulation--count. Adopting the definition used by Morse (1966), the n term may be taken to indicate a quantity of the response dimension, and any dimension may be specified by the generic ratio relation. Therefore, one unit of responding is related to one unit of stimulation, but any unit may be specified without changing the essential features of the relation.

Procedural Translation

All four of the contingencies shown in Figure 1 may be arranged for interval schedules. In the examples presented in Figure 4 the response requirement (r) is maintained at one for response count as well as for response duration. However, the generic ratio component is a relation between units of the specified response dimension and units of the specified reinforcing, consequent-stimulus dimension, and those units may be of the dimensions of count or duration. Response count related to consequent-stimulus count is the traditional interval contingency. When the relation is between response duration and consequent-stimulus count (D-C), this relation can be described as follows: the first second of responding after the interval is over produces a reinforcer. When the relation is between response count and consequent-stimulus duration (C-D) the first response following the interval produces one second of the reinforcing stimulus. Finally, when response duration is related to consequent-stimulus

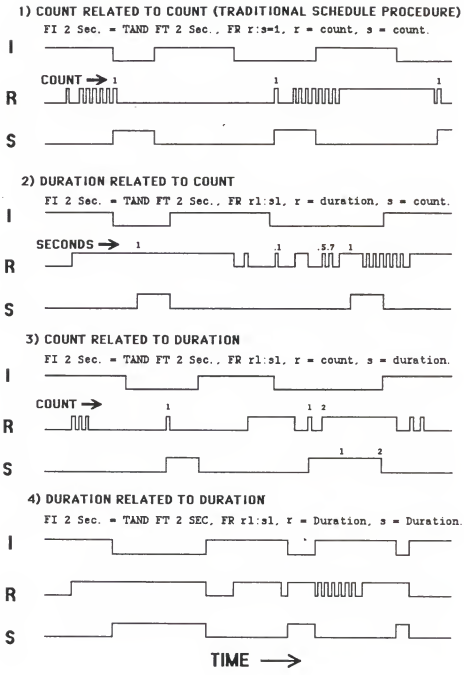


Figure 4. Representation of the four fixed-interval schedules incorporating count and duration as discontinuous and continuous response and consequent-stimulus dimensions. Events are occurring when the trace is deflected upward and not occurring when the trace is deflected downward.
Note: I=interval, R=response, S=stimulus projector.

duration (D-D), each second of responding following the interval produces one second of stimulation.

Figure 4 represents these schedules graphically using a two-second interval value for purposes of illustration. The tracings illustrate the relation of events under the four possible schedule contingencies incorporating duration and count as response and reinforcement dimensions. The traces are labeled as I, R, and S, corresponding to the interval, response, and consequent stimulus respectively. An upward deflection of the trace indicates the beginning of an event, which continues until the trace is deflected downward. The horizontal length of the event trace corresponds to the duration of the respective event.

Count-Count. Under the fixed-interval schedule relating response count to reinforcement count, reinforcement is contingent on the first response initiation after the expiration of the interval "I". In correspondence with traditional procedures, only the first response after the interval is counted toward reinforcement and responses during the stimulus period are ignored. Duration is formally irrelevant to the contingency.

This schedule contingency is illustrated in the top panel of Figure 4. Responses during the interval have no effect on meeting the requirement for reinforcement. Following the end of the interval, a single momentary response, labeled as "1", produces the onset of the consequent stimulus (S). The consequent stimulus is an event of fixed-duration. Another interval begins following the offset of the stimulus. The second reinforcing stimulus is obtained by a single

short response emitted some time after the interval is over (again labeled "1"), and responding resumes before the stimulus has ended. The interval again resumes on the offset of the stimulus. A response of long duration is emitted that extends beyond the end of the interval, but does not produce the stimulus because it was initiated before the interval expired. The stimulus is produced by the next response initiation; the first response initiated after the interval expires. Three patterns of responding are illustrated in this panel: a high rate of responding, a low rate with a single response emitted at the end of the interval, and a low rate with long duration responses. The later two patterns may postpone reinforcement beyond the minimum inter-reinforcement time determined by the interval value.

Duration-Count. Under this contingency after the interval expires, duration of responding produces consequent stimulus events on a one-to-one ratio. Schedules relating a continuous and a discontinuous element (i.e., duration and count) pose special problems in their procedural translation. Because the fixed interval is initiated following the termination of the reinforcing stimulus, and because responding during the interval does not count towards reinforcement, further response duration during the consequent stimulus period cannot produce an additional reinforcer.

One second of response duration following the expiration of the interval produces one consequent-stimulus event. The consequent-stimulus event is arbitrarily designated be one second long, as in the first schedule contingency that related response count to reinforcer

count; thus, the consequent stimulus is treated as a discontinuous or discrete event.

Count-Duration. Incorporating duration as the defining dimension of the consequent stimulus will allow it to vary in length from occasion to occasion. This is shown in the third panel of Figure 4. Responses during the consequent stimulus are not considered as occurring during the interval because the interval, by definition, begins timing after the termination of the stimulus. The present schedule correlates response count and consequent stimulus duration on a 1:1 basis following the expiration of the interval, in accordance with the defining features of fixed-interval schedules.

Duration-Duration. Incorporating consequent-stimulus duration into the contingency allows continuous variability in the consequent stimulus to enter directly into the contingency and produces a schedule analogous to fixed-interval conjugate reinforcement. Under this contingency, the 1:1 ratio of response duration to consequent-stimulus duration allows moment-to-moment correspondence of responding to stimulation. Prolonged responding produces prolonged stimulation. Termination of responding terminates the stimulus and restarts the interval. This contingency is represented in the fourth (bottom) panel of Figure 4. The interval begins timing after the termination of the consequent stimulus making it possible for the inter-reinforcement interval (from stimulus onset to stimulus onset) to vary widely when responding produces long consequent-stimulus durations. Once responding ceases, the consequent stimulus is terminated and the interval starts. The next consequent stimulus may

be produced either by initiating a response after the interval has expired or by a long duration response extending beyond the expiration of the interval. Neither the duration or the number of responses emitted during the interval influences the presentation of the consequent stimulus.

General Methods

Subjects

Subjects were volunteers recruited from the introductory psychology subject pool, and they participated as partial fulfillment of a research participation requirement for that course. Subjects were assigned to experimental conditions on the basis of the order of their recruitment.

Apparatus

The apparatus was housed in a wooden cabinet. The front of the cabinet, facing the subject, contained a translucent screen. The manipulandum was a painted Plexiglas wheel eight inches in diameter and one-half inch thick that was mounted to a sloping panel beneath the screen. The wheel could be turned in either direction. Figure 3 shows the experimental apparatus. A 7-W, green lamp was located in the bottom left corner of the screen. A response was counted when the wheel was rotated in either direction with a force of at least 142 gm for a distance of at least 1 cm. The force was calibrated by suspending a weight from the perimeter of the wheel at the 3 o'clock

position and adjusting the tension on a brake until the weight dropped 1 cm.

The consequent stimuli consisted of text projected one line at a time onto the screen by a motorized film projector (reading machine). The projector was mounted inside the cabinet and behind the screen, and projected a 2 X 20-cm image onto the center of the screen at a rate of 55 lines per minute. The film strips consisted of reading passages of controlled reading difficulty (Grade 12). The film advanced only when the projector lamp was illuminated so all lines could be read. Printed comprehension tests were used. Each test contained ten multiple-choice questions with four choices per item.

Experimental sessions were conducted in an 8 x 10-ft room containing the cabinet and a chair at one end. The room was illuminated by florescent lighting at "office levels". Electro-mechanical control and recording equipment was located in an adjacent room. Subjects wore sound-attenuating head phones, and were alone in the room for the entire session. The experimenter observed the subjects through a one-way glass panel throughout the session.

General Procedure

All subjects were treated in a similar manner, and received the same stimulus materials, comprehension tests, instructions, and general procedures. Each subject was exposed to one of the four schedule types. Performance was evaluated for stability by visual inspection of the cumulative records, but time constraints necessitated abbreviated exposure to some parameter values. Subjects served for periods of 60 min per day for 1 to 4 days, depending on

availability. Sessions generally lasted for one reading passage or for a maximum duration of 30 min.

On the first day, subjects were given a copy of the instructions (see appendix) and were instructed to read silently while the experimenter read orally. Instructions directed the subject to read the passage and described the comprehension test but did not describe the contingencies or indicate how the wheel should be manipulated. Any questions were answered by repeating the pertinent part of the instructions or by saying "it will become clear later." A copy of the instructions remained in the room with the subject during all sessions. Sessions began after the subject was observed to be seated and wearing the headphones.

At the start of each session, the green lamp was illuminated; it remained lit until the end of the session. At the end of each session the subject was given a test form and was allowed several minutes to complete it. While the subject was completing the test, the experimenter replaced the filmstrip with a new one. After the subject had completed the test form, (s)he was given a red pencil and instructed to mark any incorrect answers while the experimenter read the correct answers orally. Any errors in scoring were pointed out to the subject as they occurred and the experimenter commented on the subject's performance on the test. Course credit was delivered after the final session.

The first session started with manual shaping of the minimal response of wheel turning. During shaping the experimenter observed the subject through the one-way glass window and operated the stimulus

projector. Approximations to the wheel turning response (reaching toward or touching the wheel) were followed by presentation of the consequent stimulus (turning the projector on) for one second. Shaping was continued until the subject moved the wheel or for a maximum of five min. If the response was not acquired after five min. using this shaping procedure, the response was modeled by the experimenter. Modeling consisted of the experimenter turning the wheel one-quarter of a turn saying, "try this." After the subject emitted minimal movement of the wheel, continuous reinforcement under the predetermined experimental contingency was instituted under the control of the automatic programming equipment. Subsequent sessions were started with the programmed contingencies in full effect.

Experiment 1: Response Count Related To Reinforcer Count

Introduction

Experiment 1 was designed to demonstrate performance under contingencies equivalent to a traditional fixed-interval schedule of response count and consequent-stimulus count. The purpose of this demonstration was two fold. One purpose was to evaluate the control obtainable under the present experimental conditions by systematically replicating traditional interval contingencies. This allows assessment of the degree of generality of the results obtained using the new procedures to the existing literature on fixed-interval schedules (Sidman, 1960). The second purpose was to provide a standard for comparing the performances from the new schedules that systematically diverge from the count-count or traditional schedule

contingency. The strategy of Experiment 1 was to examine performance of several subjects at as many interval values as possible within the 2-4 hours of experimental participation obtainable from each subject.

Of principal interest was the patterning of the cumulative response-count records. To the extent that the cumulative recordings resembled patterns obtained from more traditional procedures, similar processes may be assumed. Possibilities include the classical patterns characteristic of preparations using discrete responses and reinforcers and non-human subjects. Such patterns include evidence of temporal control such as either pause and "run" responding (Branch & Gollub, 1974) or scalloping (Ferster & Skinner, 1957), or other characteristics of fixed-interval responding such as variations in the numbers of responses per interval (Zeiler, 1977; 1979). Other possibilities, peculiar to human performances under fixed-interval schedules, are high, steady rates that are not sensitive to the length of the interval, and very low rates in which only a single response is emitted each interval (see Lowe, 1979, for a review).

Because of the exploratory and inductive nature of this work, some parameters required adjustment to arrive at workable values. The minimum length of the fixed-duration stimulus presentation was varied in order to determine levels for use with the present procedures.

Method

Subjects. Eight subjects were recruited and assigned to conditions as described under the General Methods section.

Apparatus. The apparatus and instructions were as described under the General Methods section.

Procedure. With the exception of the specific experimental contingencies, the procedures were as described in the general procedure section. The number of sessions in which each subject participated under the different schedule values is presented in Table 1. Subjects were generally exposed to increasing interval values with the exceptions of ICC4 and ICC6. The interval requirement for subject ICC4 was first increased to 10 s then to 25 s, then decreased again to 10 s. The interval requirement for subject ICC6 was increased to 10 s and 25 s, decreased back to one s, and increased again to 10 s. The bracketed numbers in Table 1 indicate the number of these redetermination sessions. Only subject ICC8 required modeling of the first response. Stability was assessed by visual observation of the cumulative records.

The projector remained on for a constant duration each presentation. This period was 2 s for subjects ICC3, ICC7, & ICC8, except at FI 30 when it was increased to 3 s to allow more reading time. For the remaining five subjects, the consequent-stimulus duration was 5 s except at the longest interval value (35 s) when consequent-stimulus duration was increased to 10 s. Pilot work indicated that short consequent-stimulus durations of less than 2 seconds were problematic with this procedure as very little material could be read within each presentation. At longer interval values and short consequent-stimulus durations, the subjects were unable to complete entire reading passages. After these sessions, subjects were given the complete test sheet but were instructed to answer only those questions covering the material that they read. If the passage had

TABLE 1
Summary of Experimental Conditions

Subject	Interval Value (sec)					Consequent Stimulus Duration (sec)
	10	20	25	30	35	
ICC1	3	-	5	-	3	5[a]
ICC2	4	-	7	-	-	5
ICC3	4	-	-	-	-	5
ICC4	4[1]	-	7	-	-	5
ICC5	8	2	-	2	-	2[b]
ICC6	5[3]	-	4	-	-	5
ICC7	6	-	-	-	-	2
ICC8*	8	3	-	-	-	2

Note: Numbers indicate the number of sessions that the subject was exposed to under each interval value. Numbers in brackets indicate second determinations following sessions at higher interval values, and dashes indicate that the subject was not exposed to that interval value.
[a]Consequent stimulus duration = 10 s for FI 35.
[b]Consequent stimulus duration = 3 s for FI 30.
*Indicates subjects for which the first response was modeled.

not been finished in the previous session and there was more than 30% of the passage left, the next session was begun where the previous session had ended. Sessions were terminated at "logical" breaking points in the story line (i.e., between paragraphs). Therefore, the session duration was not based on the strict adherence to a criterion based on time or the number of consequent-stimulus presentations. This procedure allowed subjects to complete most of the passages. It also limited the session lengths to a reasonable level and preserved the natural flow of the reading material. Pilot work indicated these factors were important in maintaining reading and responding. During the first session,the interval value was increased from 2.5 s to 10 s. All subsequent sessions began with the scheduled interval at full value. The mean session duration was 11.8 min. with a range of 8.3 to 20 min.

A response was counted each time the wheel was moved the minimum amount for transduction from a stationary position. That is, one response was counted each time the subject started to turn the wheel, and the subject had to stop turning the wheel (for at least .1 s) in order to initiate another response.

The first initiation of wheel turning after the interval had elapsed turned the projector on; any response that was initiated before the interval had elapsed had to be terminated in order to initiate the criterion response. Figure 5 illustrates this relation.

The specific procedures for this contingency and the interaction of four possible patterns of performances are illustrated in Figure 5. The interval is timing when the trace labeled "I" is up, the wheel is

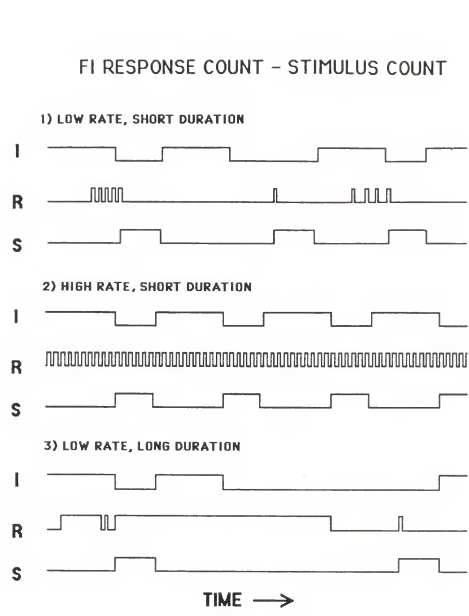


Figure 5. Representation of the Count-Count contingency presenting several possible performances and their programmed effects. Panel A shows short duration responses emitted in a pause-respond pattern. Panel B shows short responses emitted at a continuous high rate turning the stimulus projector on as soon as the interval expires. Panel C shows low rate, long duration responses; the second consequent stimulus is postponed because a response initiation does not occur until the single long response is terminated and another is emitted. Note: I=interval, R=response, and S=stimulus projector.

being turned when the trace labeled "R" is up, and the projector is on when the trace labeled "S" is up. Downward deflections indicate the cessation of these events. The passage of time is represented by distance from left to right.

Results

Cumulative Record Conventions. The count and duration records for each subject should be examined concurrently (see Figure 6 for an example). The top record of each pair, labeled "count", presents the cumulative number of responses, and was produced by stepping the pen once each time a response was initiated. The slope of the line indicates the response rate. The bottom record of each pair, labeled "duration", presents cumulative response duration, and was produced by stepping the pen once for each accumulated second that the wheel was in motion. The slope of the line indicates the rate at which seconds of responding accumulated. The maximum rate of accumulation (continuous wheel turning) produced a slope of 57 degrees.

The count and duration records of each pair are aligned such that events correspond to each other in time, in order to show the interaction of these two dimensions. Taken together, the slopes of the two graphs indicate overall characteristics of responding; a steep slope in the count record in combination with a shallow slope in the duration record was characteristic of high rate, short duration responding, equivalent slopes indicated responses of about one second in duration, and a shallow slope in the count record in combination

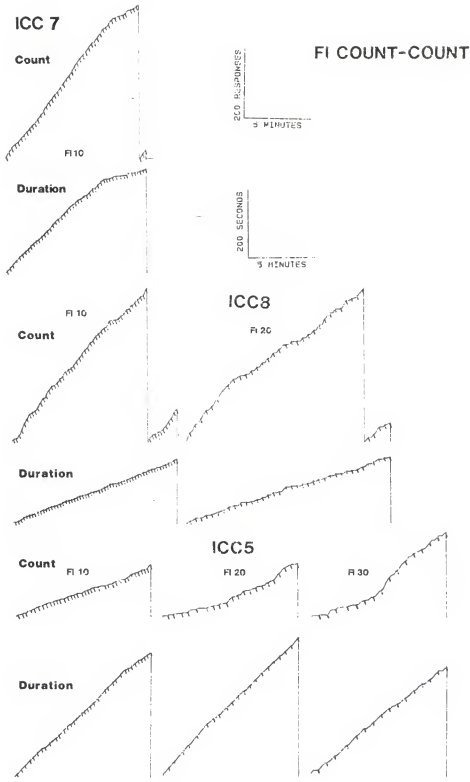
with a steep slope in the duration record indicated a low rate of long duration responses.

Local features may also be examined. For example, a horizontal or flat trace on the count record always indicated that responses were not initiated during that period; however, depending on the pattern in the duration record, a flat record may have indicated a period of no responding or a period of continuous responding. A slope of 57 degrees would indicate continuous wheel turning, and a slope of zero would indicate that no responding was occurring i.e., a pause. Horizontal or "Flat" spots on the duration record usually correspond to periods of no responding, but could correspond to brief periods of high rate-very short duration responding as can be determined by examining the corresponding count record.

The vertical "slash" marks indicate periods when the stimulus projector lamp was illuminated. The recorder motor continued to operate throughout the stimulus period. The recorders reset to the bottom of the graph when the pen reached the top of the record and at the end of the session.

Cumulative records. Cumulative records from the last session under each interval value for subjects who were exposed to consequent-stimulus durations of 2-3 s (ICC7, ICC8, ICC5) are presented in Figure 6. The top pair of records is from the last session from subject ICC7 at FI 10 s. The overall rate of response initiations was moderate and not constant throughout the session, as indicated by local deviations in the slope of the record. Fluctuations occur both in the number of responses and duration of

Figure 6. Cumulative records of response count (tracings labeled "COUNT" and cumulative response duration (tracings labeled "DURAT from the three subjects under the fixed-interval Count-Count sche using reinforcement durations of 2 s. The duration of the conseq stimulus was 3 s for Subject ICC5 at FI 30. Records are from the session under each interval value. The recording pen moved up on for each response initiated (count record) or for every second of response duration (duration record). Downward deflections indica reinforcement presentations.


ICC 7
Count
FI 10
Duration
FI COUNT-COUNT
200 RESPONSES
5 MINUTES
200 SECONDS
5 MINUTES
ICC8
Fi 10
Count
Fi 20
Duration
ICC5
Count
FI 10
FI 20
FI 30
Duration

responding per interval. A pause-respond pattern in both the count and duration records was evident in some intervals. This subject withdrew from the experiment at this point.

Similar patterns were obtained from subject ICC8 under FI 10 and FI 20. Compared with the records from subject ICC7, the overall rate of response initiations was somewhat higher, and there was greater variability in the number of responses per interval, the pause-respond pattern was more evident, and durations were shorter as indicated by the shallow slope of the cumulative duration record. Brief pauses were evident early in many intervals. The pause-respond pattern was more marked in both the cumulative count and duration records under FI 20 than under FI 10.

The bottom pairs of records were from subject ICC5 at interval values of 10, 20, and 30 s. The records from ICC5 present a different response pattern. There are fewer deviations in the slope of the duration records but many in the response initiation records (especially under FI 10 and FI 20). This pattern indicated that responses were of relatively long duration and that the subject spent most of the session continuously turning the wheel. This seems less true under FI 30 where deviations were evident in the slopes of both records indicating periods in which no responding occurred (pauses). Note that there is some difference in the horizontal spacing of the slash marks indicating that some of the consequent stimuli were not produced as soon as the interval elapsed. The cumulative response count record from FI 10 s showed a respond-pause pattern in which responses tended to be initiated more frequently early in the interval

and less frequently closer to the stimulus presentation, and the wheel was often turned continuously throughout the interval, sometimes delaying the presentation of the consequent stimulus. This pattern indicated that the horizontal places in the count records were periods when no responses were initiated but when the wheel was being turned continuously. This performance changed somewhat at FI 30; response count continued to decelerate during some intervals, but accelerated during others. The duration records showed corresponding periods of zero slope indicating that no responding occurred.

Cumulative response count and duration records from subjects for whom longer stimulus presentations were programmed are presented in Figure 7. These records were produced in the same way as those in Figure 6.

Records from subject ICC1 displayed a relatively high rate, short duration pattern similar to that from subjects ICC7 and ICC8. The number of responses per interval was quite variable under FI 25 and 35. The records from subject ICC4 also show a pattern of very short duration responding, but the rate of response initiations was very low. Often only a single response was emitted at the end of the interval, although intervals in which several responses occur towards the end of the interval were also common. Records from subject ICC1 showed a pattern similar to that of subject ICC4, but durations were somewhat longer, especially at FI 10 in which several of the intervals were prolonged because of long duration responding early in the session. At FI 20 the response initiations are not as clearly clustered towards the end of the intervals as for subjects ICC7, ICC8,

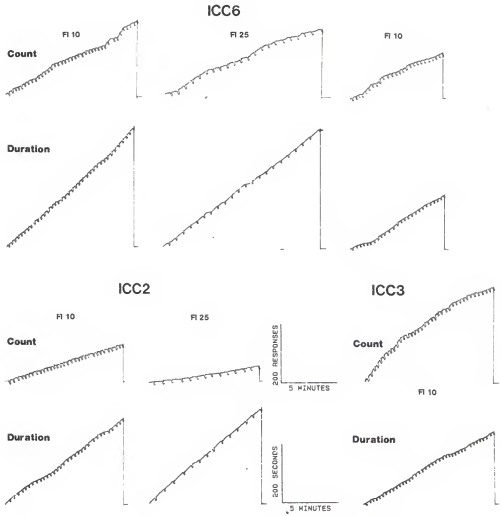


Figure 7. Cumulative records of response count (tracings labeled "COUNT") and cumulative response duration (tracings labeled "DURATION") from the five subjects receiving longer reinforcement durations under the fixed-interval Count-Count schedule. Reinforcer durations were 5 s except for subject ICC1 under FI 35 when the reinforcer duration was 10 s. Records are from the last session under each interval value. The recording pen moved up once for each response initiated (count record) or for every second of response duration (duration record). Downward deflections indicate consequent-stimulus presentations.

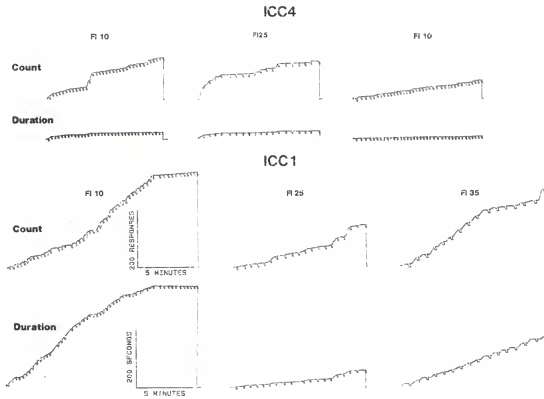


Figure 7 -- Continued.

and ICC4. Under FI 35 response initiations were more frequent towards the end of the intervals early in the session but pauses in responding and some long duration responses occurred in the latter part of the session.

Records from subjects ICC6, ICC2, and ICC3 showed patterns similar to those of subject ICC5 in the previous figure. Response rates were relatively low and durations were long. The slope of the duration record indicated that the wheel was being turned constantly throughout the interval with single response initiations early in the interval and at the end of the interval. The record from subject ICC3 showed a higher rate of response initiations and somewhat more deviations in the slope of the response count and duration records but this subject still tended to turn the wheel for most of the session.

Summary Data. These performances are represented quantitatively in Figure 8, which presents the average response rate, the average response duration, and the percent of the interval spent responding for each session. All data were from the interval periods only. The left ordinate is logarithmic and provides the scale for response rate (open symbols), measured as the number of responses per minute, and the mean response duration (closed symbols), measured as the number of seconds per response. The right ordinate provides the scale for the percent of the interval spent responding ("X").

Two general patterns are evident in these data. Performances of the subjects presented in the left panels of Figure 8 (subjects ICC1, ICC4, ICC7, & ICC8) were generally similar to each other; the rate of response initiations was relatively high, the response

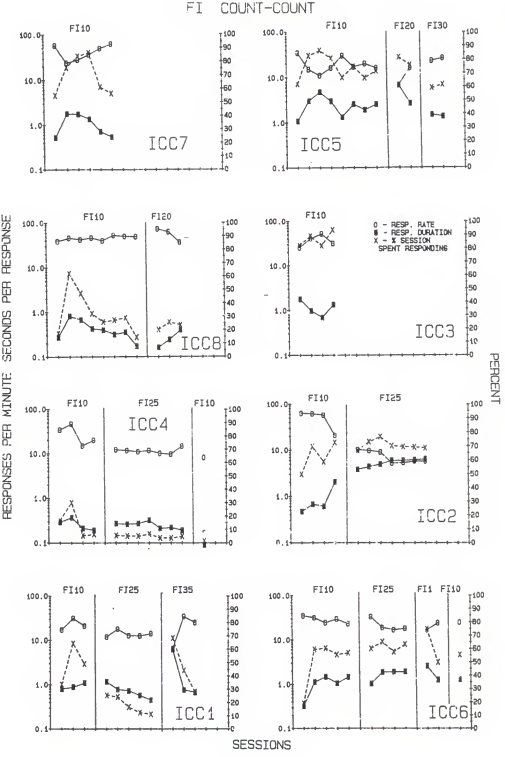


Figure 8. Session means for all sessions for each subject under the FI Count-Count schedule. Data are from the interval period only. Note the logarithmic left ordinate.

durations relatively short, and the percentage of the session spent responding was low or decreasing as for subject ICC7. The second pattern was exhibited by the subjects presented in the right panels of Figure 8 (subjects ICC5, ICC3, ICC2, & ICC6); in general response rates were comparable, but the response durations were relatively longer and the percentage of the session spent responding was higher than for subjects in the left panels.

Table 2 presents values of several performance measures from the last session under each interval value for each subject. For all six subjects exposed to both FI 10 and FI 20, the response rate was higher under FI 20; response durations were lower under FI 20 for four subjects, and higher for another subject. Post-reinforcement pauses were longer under FI 20 for five subjects (but to varying degrees) and slightly shorter for one subject.

Discussion

The fixed-interval Count-Count schedule related response and consequent-stimulus elements in terms of their countability and were intended to represent interval schedules under the present procedures which are in some ways relatively novel. To the extent that the Count-Count schedules generated patterns of responding that are reasonably comparable to those generated by more familiar fixed-interval procedures, the Count-Count schedules provide the basis for generalizing the present findings to the existing schedule literature.

Several features of the present results were similar to performances under fixed-interval schedules reported in the general literature. The record from subject ICC8 at FI 20 displays many

TABLE 2
Measures of Performance Under FI Count-Count

Subject	FI	Response Initiation Rate (Resp/min)	Average Response Duration (Sec)	Mean PRP (Sec)	% Interval Spent Responding	Total Responses Per Interval	Total Duration Per Interval	Quarter-Life	% Session in Stimulus
ICC1	10	21.1	1.1	.6	49.0	5.0	7.0	.17	26.0
	25	14.1	.4	7.9	11.1	6.9	3.2	.16	14.9
	35	25.1	.7	7.3	28.1	16.8	11.2	.42	19.2
ICC2	10	21.0	2.1	.5	72.3	4.0	10.3	.41	26.1
	25	5.8	6.5	.6	68.4	3.5	24.6	.48	13.3
ICC3	10	31.6	1.4	.8	93.4	6.6	11.8	.24	28.5
ICC4	10	20.1	.2	8.5	6.4	4.2	.8	.47	28.6
	25	14.8	.2	24.2	4.8	7.0	1.4	.44	15.4
	10	8.2	.1	12.4	1.3	1.7	.2	.67	28.3
ICC5	10	16.6	2.6	.4	71.9	4.0	10.7	.89	9.1
	20	16.7	2.7	.2	76.2	7.4	20.3	.25	7.7
	30	27.0	1.4	.7	61.5	15.2	21.1	.26	8.4
ICC6	10	23.0	1.4	1.5	56.8	5.5	8.1	.37	26.8
	25	18.1	1.9	1.5	63.2	10.6	22.2	.28	13.9
	10	24.5	1.3	1.4	55.4	5.5	7.5	.36	26.7
ICC7	10	61.2	.5	1.8	56.3	11.6	6.4	.24	11.2
ICC8	10	48.5	.2	2.8	14.3	9.1	1.6	.44	11.1
	20	36.3	.4	8.8	23.5	13.3	5.2	.43	9.0

Performance measures from the last session of each interval value for all subjects under the FI Count-Count Schedule.

classic features of fixed-interval performance including post-reinforcement pauses, occasional scalloping, and second-order effects. All subjects (except possibly ICC2) show signs of some characteristics of fixed-interval performance. The quarter-life values for several subjects (ICC2, ICC4, and ICC8; and ICC6 and ICC1 at FI 10 and FI 35 respectively) indicate temporal patterning in response initiations. The performances certainly display characteristic dynamic output components, characteristic of performance under fixed-interval schedules, such as variation in the number of responses per interval with some degree of alternation of intervals containing many responses and those containing very few responses (Zeiler, 1979). Post-reinforcement pauses often increased with increased interval values (e.g., Dews, 1969).

Cumulative records frequently showed patterns typical of fixed-interval performance from non-human subjects during transition periods such as during early training or following an increase in the interval value (e.g., Ferster & Skinner 1957). Examples of such performances in the present records are intervals with negative acceleration, "grainy" appearance of records, and pauses in addition to the initial post-reinforcement pause (e.g., subject ICC5, ICC6, & ICC1).

Given the relatively short exposure to the interval contingencies compared to studies using animals as subjects, this is not surprising. Considerable exposure to fixed-interval schedules is required before stable scalloped patterns emerge; even late in training, after hundreds of sessions, deviations such as those seen in the present records have been reported to occur frequently with pigeons (Ferster &

Skinner, 1957). Such patterns have also been reported with human subjects after relatively long training (Long, Hammock, May, & Campbell, 1958; Lang, 1964; Gonzalez & Waller, 1974). The results of Experiment 1 from most subjects may be considered as characteristic of behavior during a transitional state rather than steady state performance and may not yield meaningful quantitative comparisons with interval performances from studies of steady state performances. Comparisons across interval values in the present study may not be indicative of steady state fixed-interval performance under the present procedures. Although overall patterns did not change dramatically from phase to phase, quantitative comparisons across interval values must be made with caution, as differences may reflect the influence of increased experience rather than reliable differences due to the schedule parameters. This information should be used when evaluating performances on the other experimental schedules; i.e., that performances may be behavior in transition. The patterns can be compared, as such, within and across subjects and used as a standard for comparison of performances under other contingencies employing the same general procedures.

It is noteworthy that few of the records resemble the high, constant rate performance or the very low rate, one response per interval, performance that is often considered as "typical" human fixed-interval performances (Lowe, 1979; but see Long et al. 1958; Perone, Galizio, & Baron, 1987; 1988; Weiner, 1983). Some subjects did show a low-rate pattern, but even in the records of ICC2, with the lowest response initiation rate, do not reliably show a single

response at the end of each interval. The duration of the sessions, the length of the intervals and the total length of participation are about average for studies using human volunteer subjects (Bernstein, 1988), and these variables cannot account for the absence of "typical" human performances. Furthermore, these typical human performances are usually in evidence very early in training (often within the first session) and had ample time to develop in the present study. The use of the reading material as the reinforcing stimulus may have served as a kind of distraction task that interfered with covert self instruction (Lowe, 1979); however, the reading material was not present during the interval when the rules would be in operation. The type of response/manipulandum which allowed or even promoted variability in response duration may be responsible; both the type of response and the reinforcing stimulus are relatively different from usual experimental procedures.

While response counts showed patterns similar to those produced by non-human subjects under more standard experimental arrangements, response duration did not--at least to the same degree. Two patterns of response duration were seen in the cumulative records: one of short response durations that mirrored the emission of response initiations; the other of relatively long response durations (up to six seconds) that filled most of the time between response initiations.

Longer response durations were produced in four of the eight subjects, but long response durations were not required for reinforcement. At the moment of reinforcement, the consequent stimulus was presented immediately following a response initiation.

Thus, reinforced responses were quite short. However, the performance of subjects ICC2 and ICC5 differed from the others in the group in that they tended to respond throughout the consequent-stimulus presentation and/or the interval. While the consequent-stimulus presentation is temporally contiguous with the initiation of the response, it is also correlated with ongoing responding, and duration may have been spuriously reinforced along with response initiation. Long response durations may reflect the working of a secondary variable operating in conjunction with the relatively unrestricted response definition, such as reinforcement of long response durations similar to reinforcement of long IRT's (i.e., long duration responses are more likely to be followed by reinforced responses than short duration responses). The appearance of longer response duration in the performance of some subjects may be due to chance variations in the topographies of early reinforced responses that are allowed to persist under interval schedules.

Another possibility is that the patterns of continuous wheel turning durations are indicative of the operation of self-generated verbal instructions or rules, and the continuous wheel turning is analogous to the high, steady rate of responding sometimes displayed by human subjects under fixed-interval schedules. In this case, the variability in response count would reflect a lack of control of that dimension by the schedule contingencies. One argument against this latter interpretation is that while performances did not change radically with experience, performance did vary in subtle ways such as fluctuations in rate and duration across sessions as shown in Figure 8

and the record of subject ICC5 from FI 20 to FI 30. Note that the duration record from subject ICC5 at FI 30 showed more frequent deviations throughout the interval and that these were correlated with the pattern of response initiations. This type of gradual change is not a benchmark for the operation of a rule for constant wheel turning, and may be better interpreted as drifting of spurious control of long response durations by the contingency.

It appears that the count records of subjects exhibiting short duration responding show more features of fixed-interval schedule performances from animal subjects as reflected in pause respond patterns, second order effects, fewer patterns of negative acceleration within the interval, fewer pauses within runs and higher quarter-life values than records with long duration responses. This may indicate relatively stronger control of the schedule over response count.

Experiment 2: Response Duration Related to Reinforcer Count

Introduction

The purpose of Experiment 2 was to describe responding under fixed-interval schedules in which reinforcement is directly contingent on the property of response duration, and response count is treated as a formally irrelevant dimension. This contingency is shown schematically in Figure 9 (the conventions are as described for Figure 5). Under this contingency, after the interval expired, duration of responding produced consequent-stimulus events on a 1:1 ratio. One

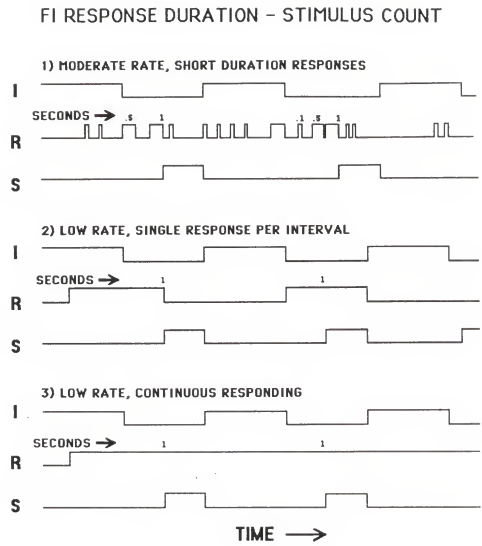


Figure 9. Representation of the Duration-Count contingency presenting several possible performances and their programmed effects. Panel 1 shows short, variable duration responding in a temporal pattern of pausing and responding. Panel 2 shows a single response emitted near the end of the interval. Panel 3 shows very low rate, long duration responses. The higher rate performances (1 & 2) have the potential for prolonging the interval if over-long latencies or IRT's occur. Note: I=interval, R=response, and S=stimulus projector.

second of responding produced one consequent-stimulus event (for the purposes of illustration the consequent-stimulus event is one second long). As in the Count-Count contingency of Experiment 1, responding during either the consequent stimulus or the interval did not count toward reinforcement, and the consequent stimulus was treated as a discrete event. That is, the duration of the consequent stimulus did not vary as a function of responding.

Methods

Subjects. Four subjects served in Experiment 2. They were recruited as described for Experiment 1.

Apparatus. The apparatus was the same as used in Experiment 1.

Procedure. All instructions, stimuli, test materials, and experimenter-subject interactions were as described under the general methods section. All subjects were exposed to FI 10 and 25, and the consequent-stimulus duration was 5 s. Two subjects were also exposed to FI 35; one of these was also exposed to FI 45 and 60, and the consequent-stimulus duration was 10 s for these sessions. The number of sessions and consequent-stimulus duration under each value for each subject is presented in Table 3. The initial response was shaped for all subjects.

Results

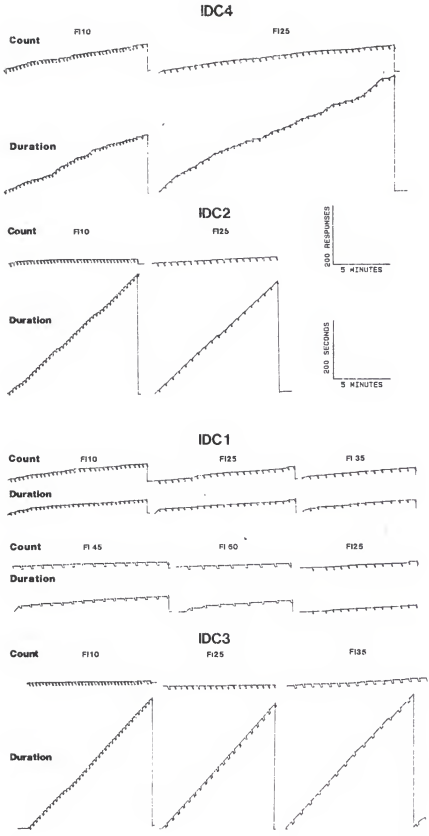
Cumulative response count and cumulative response-duration records for all subjects are presented in Figure 10. Records were from the last session of each interval value for each subject, and were produced as described in Experiment 1.

TABLE 3
Summary of Experimental Conditions Under FI Duration-Count

Subject	Interval Value (sec)					Consequent Stimulus Duration (sec)
	10	25	35	45	60	
IDC1	2	2[2]	2	1	1	5[a]
IDC2	3	7	-	-	-	5
IDC3	3	4	2	-	-	5[b]
IDC4	4	4	1	-	-	5[b]

Note: The numbers below the interval values indicate the number of sessions that the subject was exposed to under that interval value. Numbers in brackets indicate second determinations following sessions at higher interval values, and dashes indicate that the subject was not exposed to that interval value.
[a]Consequent stimulus duration = 15 s at FI 45 and FI 60.
[b]Consequent stimulus duration = 15 s for FI 35 only.

Figure 10. Cumulative records of response count (tracings labeled "COUNT") and cumulative response duration (tracings labeled "DURATION") for all subjects under the fixed-interval Duration-Count schedule. Records are from the last session under each interval value. The recording pen moved up once for each response initiated (Count record) or for every second of response duration (Duration record). The pen defected downward during stimulus presentations. Consequent-stimulus presentations were 15 s long for subject IDC1 at FI 45 and FI 60, and for subject IDC3 at FI 35 and 5 s for all other subjects and conditions.


IDC4
Count
FI10
FI25
Duration
IDC2
Count
FI10
FI25
200 RESPONSES
5 MINUTES
Duration
200 SECONDS
5 MINUTES
IDC1
Count
FI10
FI25
FI 35
Duration
Count
FI 45
FI 60
FI25
Duration
IDC3
Count
FI10
FI25
FI35
Duration

The count records from all subjects showed very low response rates. The cumulative response duration records are somewhat different across subjects, both in the overall amount and the distribution of response duration. Slopes in the cumulative duration records were consistently steeper than slopes of the count records for three of the four subjects, indicating long response durations. The fourth subject (IDC1) frequently emitted only a single second of responding at the end of each interval.

A pause-respond pattern was evident in the duration records from subjects IDC1 and IDC4, and the number of seconds per interval was variable for these subjects. Periods of no responding (pauses) followed by periods in which response duration accumulated steadily were frequent (i.e., a pause-respond pattern with respect to response duration rather that count). These patterns are more easily seen in records from longer interval values. The records from IDC4 and IDC1 clearly indicated that the patterns of the duration records were independent of the patterns of the response count records, and intervals with many seconds of response duration do not have corresponding intervals of high response counts. Usually a single response initiation occurred well into the interval followed by a period of constant responding until the next consequent-stimulus presentation.

Two subjects showed little deviation in the duration records. Subject IDC2 paused only briefly following each consequent stimulus, followed by a single response initiation and the accumulation of response duration at a steady rate during which time only the single

response initiation occurred. Subject IDC3 responded continuously throughout the entire session, emitting few responses; additional sessions were not conducted because the subject withdrew from the experiment. For all subjects, once a response was emitted, it generally continued until the stimulus was produced.

Session means of response rate, response duration, and the percent of the interval spent responding are presented in Figure 11. Data are from the interval periods only. Response initiation rates, response durations, and the percent of the interval spent responding were stable for subjects IDC4 and IDC2 at FI 25, and only the percent of the session spent responding was stable for subject IDC3. Subject IDC1 spent few sessions at any interval value, but was exposed to many values. The rate of response initiations generally decreased and response durations generally increased with increased interval values. For subject IDC1, the percent of the interval spent responding changed little as interval duration increased.

Table 4 presents data from the last session under each interval value from each subject. There was no systematic change in the mean response rate or duration from FI 10 to FI 25. With respect to response duration: two subjects, IDC2 IDC3, showed no temporal control, and a strong effect of the contingency between response duration and reinforcement. Two subjects showed control by temporal aspects of the schedule as well as effects of reinforcement of duration, although performance of subject IDC1 was relatively more restricted by temporal control.

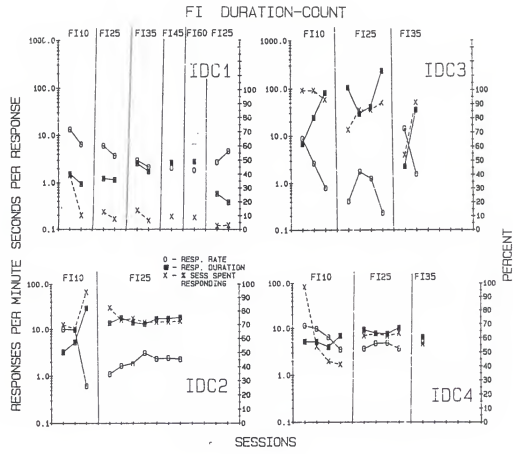


Figure 11. Session means for all sessions for each subject under the FI Count-Count schedule. Data are from the interval period only.

TABLE 4
Measures of Performance under the FI Duration-Count Schedule

Subject	FI	Response Rate in Interval (R/min)	[a]Mean Response Duration (Sec)	Mean PRP. (sec)	Percent Interval Spent Responding	Percent Run Spent Responding	Total Responses Per Interval	Total Seconds Per Interval	Quarter-Life	% Session in Stimulus
IDC1	10	6.5	0.9	15.4	10.1	85.6	1.9	1.8	.65	22.2
	25	3.7	1.2	25.2	7.3	45.5	1.8	2.1		15.0
	35	2.2	1.7	32.2	6.2	42.3	1.4	2.4		11.8
	45	2.1	2.6	38.7	9.1	69.8	1.5	4.1		17.5
	60	2.0	2.8	41.8	8.6	24.0	2.0	5.6		13.9
	25	4.6	0.4	29.1	7.8	8.4	3.5	1.3		8.7
IDC2	10	1.9	29.0	0.8	94.1	100.0	0.4	11.9	.26	28.5
	25	2.4	18.1	1.3	72.5	89.3	1.2	21.0	.27	15.1
IDC3	10	0.8	62.2	0.4	98.8	100.0	0.2	10.8	.55	29.6
	25	0.2	233.0	0.2	98.1	100.0	0.1	24.5	.24	21.0
	35	1.6	35.1	0.2	94.6	95.1	0.9	33.1	.43	21.6
IDC4	10	6.5	4.0	5.7	43.3	75.4	1.4	5.8	.33	26.3
	25	4.8	7.6	7.8	61.2	69.3	2.2	16.9	.33	15.8
	35	5.2	6.5	6.0	55.7	66.8	3.1	20.1	.40	21.8

Performance measures from the last session of each interval value for all subjects under the FI Duration-Count Schedule.
[a] Includes duration of responses initiated in the interval and continuing during the stimulus.

The effect of the contingency on response count was quite consistent; very few responses were emitted during each interval for any subject. The response initiation rates were substantially lower than those obtained from subjects in Experiment 1 under the Count-Count schedule.

The constant wheel turning of subjects IDC2 and IDC3 may be analogous to the high rate pattern sometimes obtained with human subjects under fixed-interval schedules (see Lowe, 1979). No instances of high constant rates of response initiations were observed under the Count-Count schedule in Experiment 1. Some authors (e.g., Lowe, 1979) attribute this pattern to self-generated verbal behavior or rules, resulting in insensitivity to the programmed contingencies (Lowe, 1979; but see Perone et al., 1987; 1988). Although self-generated rules may have played a part in the performances, it is worth noting that the rules seem to have been about response duration, or at least continuous responding, rather than count. Description of the performance as rule-governed should also include the influence of the contingencies on the speculated rule generation.

The very low rate of response initiations under the Duration-Count schedule might be related to delay of reinforcement for response initiations imposed by the requirement of the accumulation of one second of responding prior to the consequent-stimulus presentation. While it is not required by the schedule, a given response made after the interval has timed out will precede the presentation of the stimulus by at least one second. In procedures using instantaneous

discrete responses, delays of one second can greatly reduce response rates under interval schedules (e.g., Schaal & Branch, 1988); the remaining time is filled with interresponse activity (i.e., doing other things). The substantial decrease in response rate might have been produced by the potential delay from the initiation of the reinforced response to the onset of the reinforcing stimulus. However, the reason that the remaining time was filled with duration rather than no responding can be attributed to the selective enhancement of duration by the Duration-Count contingency.

Another point to be made about the one-second duration requirement is the correspondence of one second to one response initiation. The schedules may be described as Tand FT X, FR 1 schedules and the equivalence of a fixed ratio of one response initiation and one second of responding is not known. When short ratios are introduced in Tand FI, FR X schedules, response rates are increased (Ferster & Skinner, 1957, Findley, 1962), and short bursts of responses are evidenced in the interval performances. It is possible that the amount of wheel turning is due to the functional size of the duration requirement relative to a single response initiation (i.e., a relatively larger amount of response duration is required than response count).

The differences in performances generated by duration-based relations may present a method for analyzing the contribution of various response dimensions to behavior patterns. One advantage of the procedure is that it does not seem to impose restrictions in responding, as in interlocking schedules or synthetic schedules that

require modification of the mathematical correspondence. However, more questions have been raised than answered by the present manipulations. Experiments 1 & 2 were not performed to answer specific theoretical questions about fixed-interval performance per se, but to use the partial reinforcement procedure to illustrate better the effects of reinforcement of response duration independent of response count.

Experiment 3: Response Count Related to Reinforcer Duration

Introduction

Experiment 3 incorporates the continuous dimension of duration as the consequent-stimulus element of a fixed-interval contingency, while maintaining the traditional response dimension of count. Incorporating duration as the defining dimension of the consequent stimulus will allow the stimulus to vary in length from occasion to occasion as a direct function of the number of responses emitted following the interval. Thus, the duration of individual reinforcers is determined by the rate of responding while the consequent stimulus is present. The interval contingency provides intermittent reinforcement of this relation, allowing assessment of the effects of this reinforcement procedure on unreinforced responding during the interval and the effects of the interval schedule on reinforced responses during the consequent stimulus.

This schedule is similar to schedules of correlated reinforcement as described by Logan (1960). These studies used runway procedures and correlated the magnitude of the reward (number of food pellets)

with the speed with which rats traversed the ally. More recently, Gentry and Eskew (1984) and Buskist et al. (1988) related magnitude of reinforcement to number of responses emitted during the inter-food interval under fixed-time and fixed-interval schedules respectively. The rate of responding during the intervals increased over those of control groups, demonstrating the efficacy of these relations in controlling number of responses concurrently with the interval contingency.

The procedures used by Gentry & Eskew (1984) and Buskist et al. (1988) resemble conjunctive schedules with a response dimension of count for both the temporal schedule and a ratio relation; the reinforcer is presented after the temporal schedule requirement has been met and the magnitude of reinforcement is related to the number of responses emitted during the preceding interval. The present schedule differs from these by directly relating reinforcement duration to response count under a fixed-interval schedule in that responding during the interval had no effect on reinforcement. As such, it may be considered as a fixed-interval schedule of correlated reinforcement and a manipulation of the way reinforcement is presented, rather than as a change in the nature of the interval contingency. As such it may be conceived of as a tandem FT, conjugate reinforcement schedule, as a traditional fixed-interval schedule may be conceived of as a Tandem FT, FR 1 schedule.

Traditionally under interval schedules, response initiations during the consequent-stimulus presentation do not affect reinforcement. Under this Count-Duration schedule, however, the

reinforcing stimulus can have its behavioral effect and not interfere with the capacity to respond. The present schedule correlates response count and consequent-stimulus duration on a 1:1 basis following the expiration of the interval.

Figure 12 presents schematic representations of possible relations. The events are the same as described for Figure 5. Each response initiation after the interval had expired prolongs the consequent-stimulus duration for an additional one second. The interval starts timing at the end of the consequent stimulus. Thus, it is possible for the subjects to maintain the presence of the stimulus for the entire session following the initial interval. High rate-short duration responding will prolong the stimulus as indicated in the top set of traces. The second set of traces illustrates the same pattern with longer duration responses, the rate is lower not because of longer IRT's but because of longer duration responses. A slightly lower rate of short duration responses may not prolong the consequent stimulus and/or the interstimulus interval may be extended as illustrated in the third set of traces. Slightly longer duration responses can lead to a similar pattern as illustrated by the fourth set of traces.

Unlike the contingencies in Experiments 1 & 2 in which parameters of the reinforcing stimulus were held constant within each session, under the present schedule the duration of the reinforcing stimulus can vary with responding. The minimum consequent-stimulus duration was set at one second and the actual duration of the consequent stimulus is determined by performance.

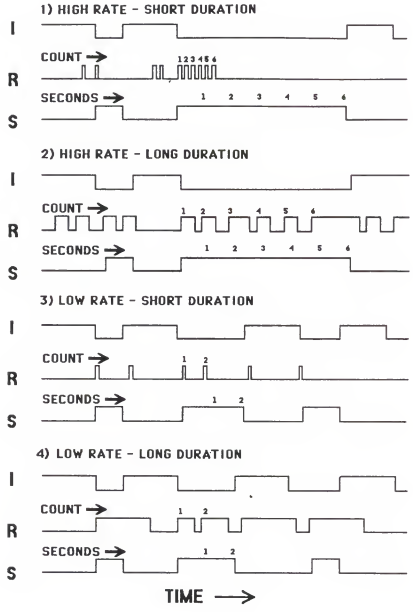


Figure 12. Representation of the Count-Duration contingency presenting several possible performances and their programmed effects. Panel 1 shows short duration-high rate responding in a pause-respond pattern. The numbers above the response line correspond to the one-second presentations of the consequent stimulus that they produce. Panel 2 shows an equal rate of longer duration responses. Panel 3 shows low rate, short duration responding. Panel 4 shows the same effect with a similar rate but longer duration response pattern. Note: I=interval, R=response, and S=stimulus projector.

Method

Subjects. Three subjects participated and were recruited as described above.

Apparatus. The same apparatus was used (see general methods).

Procedure. All instructions, stimuli, test materials, and experimenter-subject interactions were identical to those of Experiment 1 and 2. None of the subjects required modelling. Following shaping, the interval was held constant at ten seconds. To facilitate steady state responding subjects were exposed to a single interval value only. Sessions lasted for one complete reading passage, and the average session duration was 22.5 min. (range 10.1 to 41.1 min.).

Results

Cumulative response and duration records are presented in Figure 13. Records are from the last session for subjects IDC1 and IDC3, and from the last session prior to the equipment malfunction for subject ICD2. Final performances by ICD1 and ICD3 were virtually identical. Both subjects initiated responses at a high rate during the interval periods and during the consequent-stimulus presentations (prolonging the consequent stimulus). Subject ICD1 did not prolong the duration of the first two consequent-stimulus presentations, but the remainder of the session following the interval was spent with the consequent stimulus present. Thus, subject ICD1 encountered the interval a total of three times in the last session and subject ICD3 encountered the interval once during these sessions. The slope of the duration record

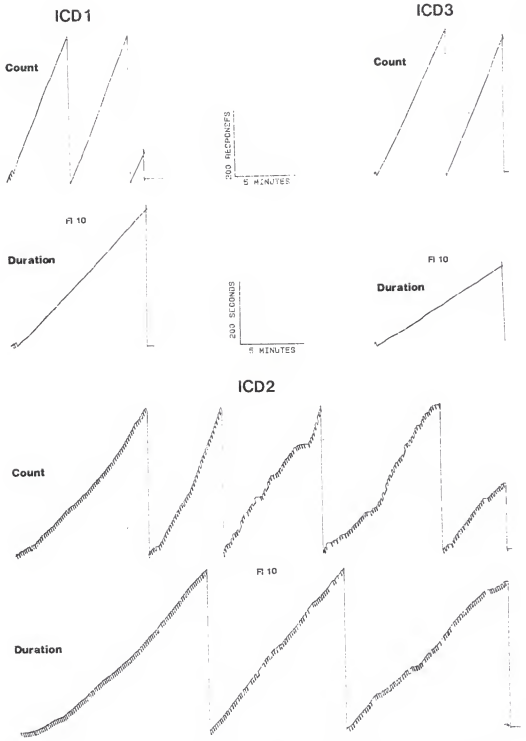


Figure 13. Cumulative records of response count (tracings labeled "COUNT") and cumulative response duration (tracings labeled "DURATION") for all subjects under the fixed-interval Count-Duration schedule. Records are from the last session under each interval value. The recording pen moved up once for each response initiated (Count record) or for every second of response duration (Duration record). Downward deflections indicate consequent-stimulus presentations.

was quite steep, but this was correlated with very high rates of response initiations indicating high rate short duration responses.

In contrast, the records from subject ICD2 showed that she prolonged the consequent stimulus at times, but not for the durations shown in the records of the other two subjects. The rate of response initiation was lower and the rate at which response duration accumulated was higher indicating longer duration responses. In addition, the count record was not smooth. The number of responses initiated during intervals and consequent-stimulus presentations was variable, and some intervals are longer than others. These were correlated with periods of no wheel turning as well as periods of continuous wheel turning.

Figure 14 presents the rates of response initiation, mean response durations, and the percent of the session and consequent-stimulus time spent responding for each session for each subject. In order to compare fixed-interval performance with performance during the consequent-stimulus period, the panels on the left side present data from the interval period only and the panels on the right side present data from the consequent-stimulus period only. Values from the last session for each subject are presented in Table 5. The two subjects that spent the majority of the last session with the stimulus present (subjects ICD1 & ICD3) emitted higher response rates and shorter response durations during both the consequent-stimulus and the interval periods than subject (ICD2) who did not reliably prolong the consequent stimulus. Response rates for subjects ICD1 and ICD3 were higher and response duration remained low or decreased during the

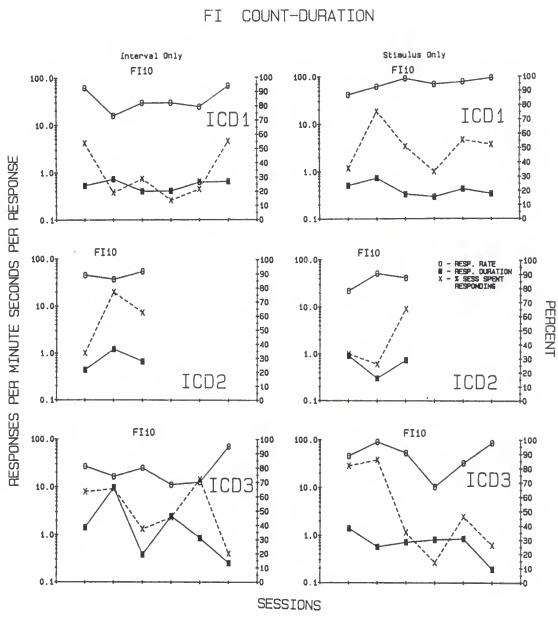


Figure 14. Session means for the FI Count-Duration schedule. Data on the left side were from the interval only and data on the right side were from the consequent stimulus period only.

TABLE 5
Performance Measures under the FI Count-Duration Schedule.

Subject	Period	Response Rate in Interval (Resp/m)	[a]Mean Response Duration (Sec)	Mean PRP. (Sec)	% Time Spent Responding	Responses Per Reinforcer	Response Duration Per Reinforcer	Quarter-Life	Mean Stimulus Duration	% Session in Stimulus
ICD1	Interval	66.7	0.6	0.1	55.3	8.5	5.3	.29	-	-
	Overall	92.6	0.3	-	52.2	247.8	83.8	_	153.9	93.7
ICD2	Interval	55.5	0.7	0.4	62.2	5.3	3.6	.23	-	-
	Overall	52.4	0.7	-	62.9	6.5	4.7	_	1.7	23.2
ICD3	Interval	70.6	0.2	2.4	20.0	4.0	1.0	.50	-	-
	Overall	86.1	0.2	-	27.0	870.0	163.3	_	602.6	99.4

Table 5. Performance measures under the FI Count-Duration schedule. Data are from the last session under FI 10.
[a]Includes duration of responses initiated in the interval and continuing during the stimulus.

consequent-stimulus period. But rates decreased and durations increased during the consequent-stimulus for subject ICD2.

Discussion

Two out of three subjects exhibited terminal performance in which the consequent stimulus was prolonged and few intervals occurred. This performance was obtained late in exposure to the contingencies, and is indicated by overall response initiation rates above 60 per minute in the graphs labeled "stimulus only" in Figure 14. Subject ICD3 reliably prolonged the stimulus in the last half of the third session (after 34.5 min. of exposure), but did not reliably prolong the stimulus on subsequent sessions until the final session. Subject ICD1 emitted high response rates and prolonged the stimuli early in training (within the second session) and maintained this pattern throughout. Note that subject ICD2 participated in the experiment for approximately the same total length of time as the other subjects but completed fewer sessions because these sessions were 3 to 4 times longer than for the other subjects. The terminal performance was notable because of the striking difference in the cumulative records from Experiments 1 and 2. This performance seems to represent maximally efficient responding under the contingency. The majority of the session was spent in the stimulus period, and provided relatively little information about interval performance.

The final session response rate during the intervals was as high or higher, and response duration lower than obtained under the schedules from Experiments 1 & 2. This level of responding was not required by the interval contingency, but high rates were required by

the Count-Duration contingency in order to prolong and maintain the consequent stimulus. Response rates for subject IDC2 were the lowest of the three subjects, but rate was still substantially higher than obtained under the previous contingencies. Note this subject did produce longer duration consequent stimuli occasionally and may have come to produce the same pattern as the other two subjects with longer exposure to the contingencies, which was prevented due to an equipment failure, yet the effect of the Count-Duration contingency on interval responding was still apparent.

Experiment 4: Response Duration Related to Reinforcer Duration

Introduction

Experiment 4 incorporated the dimension of duration into both the response and the reinforcing stimulus in the fixed-interval contingency. This allowed continuous variability in the consequent stimulus to be related directly to response duration. There were no requirements or restrictions on response initiations, making count formally irrelevant to the contingency as in Experiment 2. The 1:1 ratio of response duration to consequent stimulus duration allowed moment-to-moment correspondence of responding to consequent stimulation; prolonged responding produced prolonged consequent stimulation. Termination of responding terminated the stimulus and initiated the interval. In preserving the formal properties of the fixed-interval schedule, response duration during the interval did not affect reinforcement, and reinforcement duration was determined by the duration of responding following the expiration of the interval.

Figure 15 presents a schematic representation of the present interval contingency and illustrates examples of potential performances. The traces in Figure 15 follow the same conventions as described in Figure 5. Three possible response patterns are represented. The top panel illustrates a low rate-long duration pattern. The first response is initiated during the interval and continues until the interval is over. At that time the stimulus is presented and remains in effect until the response is terminated. The second response is again initiated during the interval and produces the stimulus sometime later. This response is considerably longer and the consequent stimulus remains in effect longer. The second panel illustrates a high rate-short duration response pattern. Responses occur throughout the first two intervals producing consequent stimuli at the end of the interval periods. The consequent stimulus duration is very short because of the short response duration and the next interval begins almost immediately. Later, pauses after the consequent stimulus occur without changing the pattern, rate, or duration of the consequent-stimulus presentations. The third panel illustrates a mixed pattern of high rate-short duration responding during the intervals and long duration responses during the consequent-stimulus presentation. Because the interval begins timing after the termination of the stimulus, it is possible for the interreinforcement interval to vary widely in the event that responding produces long stimulus durations. Once responding ceases, the consequent stimulus is terminated. The next stimulus may be produced either by initiating a response after the interval is expired

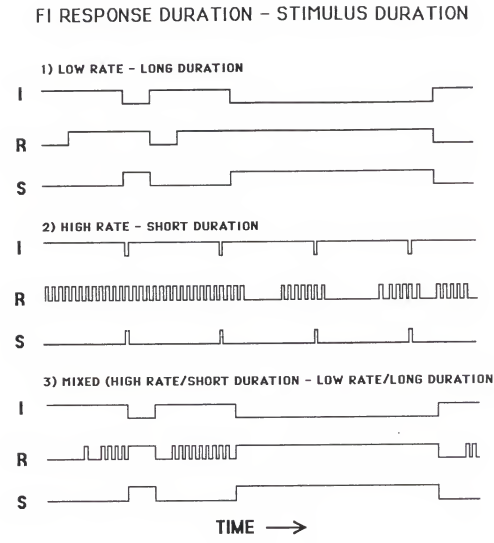


Figure 15. Representation of the Duration-Duration contingency presenting several possible performances and their programmed effects. Panel 1 shows long duration-low rate responding. Panel 2 shows short duration-low rate responding, note the short duration stimuli. Panel 3 shows mixed high rate-short duration responding during the interval and long duration responding during the reinforcement period
Note: I=interval, R=response, and S=stimulus projector.

or by a long duration response extending beyond the expiration of the interval. Neither the duration or the number of responses emitted during the interval influences the presentation of the consequent stimulus; however, the duration of the consequent stimulus is directly related to the duration of responding following the interval.

Under this contingency, the contributions of the fixed-interval schedule contingency and the pattern of responding that occurs with correlated reinforcement may be examined. The time from reinforcement presentation to reinforcement presentation is determined not only by the length of the interval, but also by the length of the reinforcing stimulus presentation. Of course, the time from the termination of the one reinforcing stimulus and the initiation of the presentation of the next stimulus may remain constant and determined by the interval value. The effect of this potentially variable inter-reinforcement time may be determined.

Method

Subjects. Four subjects were recruited as described in the general methods section. Subjects who indicated that they would serve for only one or two hours were assigned to this experiment.

Apparatus. The same apparatus used in the previous experiments was used in Experiment 4.

Procedures. All instructions, stimuli, test materials, and experimenter-subject interactions were identical to those of the previous experiments. All subjects were exposed to a single interval value (FI 10 s). Sessions lasted for one complete reading passage. The average session length was 10.83 min. (range 8 to 21.4 min.).

Results

Cumulative response count and duration records are presented in Figure 16. Records were taken from the last session for each subject. The trace directly below the cumulative response and cumulative response duration records for each subject corresponds to consequent-stimulus presentations; this line deflected downward during the stimulus, and upward during the intervals. Slash marks on the cumulative records indicate the beginning of consequent stimulus presentations. Other details of the records are identical to those described for Figures 6, 10,& 13. Very few responses were initiated during these sessions as the count record for each subject indicated, but the durations of these responses were very long. Consequent-stimulus presentations were also very long, as indicated by the trace below the count and duration records.

Subjects experienced very few intervals. Subjects IDD1 and IDD4 began a single but continuous response near the end of the first interval. Responding during the consequent stimulus was continuous, prolonging the consequent stimulus for the remainder of the session. Subject IDD2 experienced four intervals. The first two intervals contained pauses followed by several brief responses (examine the second interval), and responding was continuous during the next two intervals (beginning immediately after the initial cessation in responding). IDD3 responded continuously throughout the four intervals; the time between response cessation and initiation of the next response was very short, and no noticeable post-reinforcement pause is indicated.

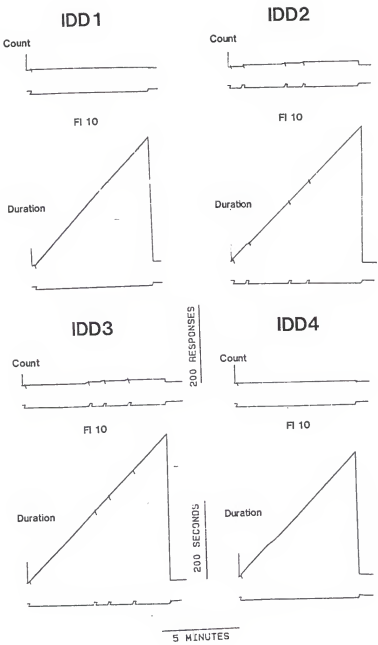


Figure 16. Cumulative records of response count (tracings labeled "COUNT") and cumulative response duration (tracings labeled "DURATION") for all subjects under the fixed-interval Duration-Duration schedule. Records are from the last session under each interval value. The recording pen moved up once for each response initiated (Count record) or for every second of response duration (Duration record). Downward deflections indicate consequent-stimulus presentations. The event pen remained deflected downward throughout the stimulus presentation.

Figure 17 presents the rate of response initiations, mean response durations, and percent spent responding for each subject for each session. The panels in the left side are from the interval periods only, and the graphs on the right side of Figure 17 were from the overall session including the consequent stimulus periods. Table 6 presents values for these and other measures taken from the last session for each subject On average, more than one response was initiated each interval making the response rates somewhat higher than the minimum of 6 per minute (one per interval), and the mean response duration during the interval was lower compared to the overall duration of responding (including the duration during the consequent stimulus). Shorter duration responses were emitted during the interval followed by a long terminal response. The percent of the session spent responding reached terminal levels of 95 to 100% by the second session for three subjects (subjects IDD1, IDD3,& IDD4) and the third session for one subject (IDD2). Overall rates tended to decrease and durations to increase across sessions for subjects IDD2, IDD3, & IDD4. Response rates decreased quickly and were extremely low. Interval performances were not as extreme as overall performance in that rates were higher, durations shorter, and less of the interval time was spent responding than for the entire session. Note that the interval schedule was in effect for a minority of the session as the subjects prolong the consequent-stimulus duration.

Discussion

Under the Duration-Duration schedule, more of the interval was taken up with continuous responding compared with performance under

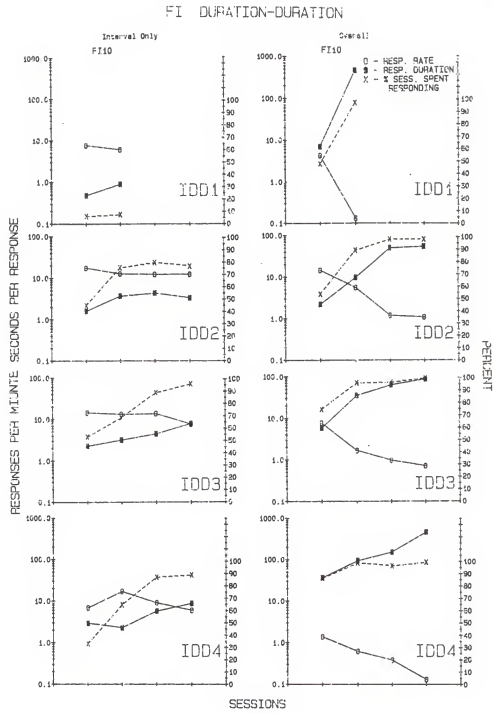


Figure 17. Session means for the FI Duration-Duration schedule. Data on the left side were from the interval only and data on the right side were from the entire session.

TABLE 6
Performance Measures under the FI Duration-Duration Schedule

Subject	Period	Response Rate (Resp/m)	[a]Mean Response Duration (Sec)	Mean PRP. (Sec)	% Time Spent Responding	Total Responses Per Reinforcer	Response Duration Per Reinforcer	Mean Stimulus Duration	% Session In Stimulus
IDD1	Interval	5.4	0.1	11.1	.9	1.0	.1	-	-
	Overall	0.1	468.9	-	97.7	1.0	468.9	468.8	97.7
IDD2	Interval	12.0	3.3	1.8	65.5	2.0	6.6	-	-
	Overall	1.1	54.5	-	98.2	8.0	436.2	102.5	92.3
IDD3	Interval	7.5	7.9	0.2	97.2	1.2	7.7	-	-
	Overall	0.7	85.7	-	99.2	5.0	428.4	97.2	90.0
IDD4	Interval	6.0	8.9	1.1	89.0	1.0	8.9	-	-
	Overall	0.1	470.7	-	99.3	1.0	479.9	461.8	97.4

Performance measures under the FI Duration-Duration schedule. Data are from the last session under FI 10.
[a]response durations during interval include only duration prior to stimulus presentation.

the Count-Duration schedule and under the Duration-Count schedule at FI 10. Another feature worth noting is the rapid development of the terminal response pattern compared to performance under the count-duration schedule.

Larger interval values were not attempted because the response patterns observed under the FI 10 indicated that longer intervals would not allow the study of enough interval cycles to meaningfully interpret their effects. Overall, the effect of the relation of response duration and consequent-stimulus duration may be to enhance response durations during the interval period thus eliminating pausing. The small number of intervals that were sampled limits general statements about fixed-interval responding per se. However, the overall session pattern is determined by the Duration-Duration schedule, and acquisition, performance levels, and patterning during the intervals are similar under the FI schedule to patterns obtained in previous research under the CRF schedule in Williams (1985). Response rates were lower and durations higher under the fixed-interval schedule than were obtained in the previous study under CRF. Based on this comparison, it appears that the FI schedule may enhance the effects of the Duration-Duration contingency. In addition, the acquisition period was shorter than those of the previous study; many of the subjects in the earlier study were emitting many responses and shorter durations after five to seven sessions. In the present study all subjects produced three or fewer consequent stimuli (or consequent-stimulus interruptions) per session on the second session. The lengths of the sessions were comparable under the two procedures.

The present schedule was similar to one used by Hendry (1962) with rats as subjects. He used discrete responses, lever presses, and correlated the amount of water reinforcement provided after the first response following the interval with the duration of the final IRT. The rates of responding were inversely related to the relation of IRT duration and reinforcement magnitude. Note that this correlated reinforcement procedure was different from the procedures used latter (Gentry & Marr, 1982; Buskist et al. 1988) in that it maintained the feature of interval schedules and placed no formal contingency on responding during the interval. This procedure is congruent with the conceptualization presented here. The response dimension was correlated with the reinforcer dimension on a fixed-interval basis directly. That is, at the end of the interval, IRT length was correlated with reinforcement magnitude and this affected the rate of responding during the interval. In the present experiment, the rate of responding was also low, but this was correlated with long response durations rather than IRT.

The performances under the Duration-Count contingency in Experiment 2 were similar to those obtained under the present contingencies in that low response rates and long duration responses were obtained during the interval. The Duration-Count contingency required that one second of responding occur following the interval, and this introduced a delay between the first response initiation after the interval and the presentation of the reinforcer. This requirement was not present under the Duration-Duration contingency, and similar results were obtained, indicating that this delay <u>per se</u>

may not have been responsible for the performances and that the results were due to reinforcement effects on duration.

PART 3
RATIO CONTINGENCIES

Introduction

Defining Features

Ratio and interval schedules differ in that interval schedules require the specification of the two terms, the passage of time (t) and a number of responses (n), while ratio schedules require the specification of a single term (n) only. The "t" term functions to determine when the response requirement will be evaluated for reinforcement. This evaluation criterion is based on the cumulative passage of time and is response independent. Ratio schedules have no such term, and the evaluation criterion for reinforcement is based solely on the cumulative number of responses emitted.

Traditionally, the response dimension of count is related to the reinforcing-stimulus dimension of count on a basis of n to one. However, the specification of discrete response and reinforcer dimensions (count) in the relation is not an inherent part of the mathematical relation, which only specifies the ratio of response units to reinforcing-stimulus units. Thus, the defining feature is the mathematical correspondence, and the description of a ratio schedule may be stated in a generic form: a schedule contingency in which a prescribed quantity of the response dimension produces a prescribed quantity of the consequent-stimulus dimension, and the

mathematical correspondence between the two is a ratio. Generically, any dimension of responding may be related to any dimension of the reinforcer or consequent stimulus.

Formal Translation

The translation to incorporate other response and consequent stimulus dimensions is fairly straightforward. It is a matter of replacing the specification of response number with a desired value of the new response dimension in the appropriate units. For example, as traditionally specified, a fixed ratio 5 schedule requires that five responses be emitted for the delivery of one reinforcer. The reinforcer is delivered as soon as the fifth response is emitted, and all other dimensions of responding are formally irrelevant to the decision to reinforce (note that this does not mean that other dimensions of responding or defining dimensions of the response do not influence performance as indirect variables or as constraints on output, Zeiler, 1977; 1979).

The schedule contingency may be modified to incorporate the response dimension of duration. Under this schedule, five units of response duration must cumulate to produce the reinforcer. If the unit of responding is one second, then the ratio may be specified as five seconds of responding to one reinforcer. The new schedule is different from the traditional FR 5 schedule in that the number of responses initiated is formally irrelevant.

A similar translation can be made along the consequent-stimulus dimension. If consequent-stimulus duration is substituted for consequent-stimulus count under an FR 5 relation, and if seconds are

used as the minimal units, then five responses produce one second of the reinforcing stimulation. Under this schedule, the consequent stimulus may vary from occasion to occasion in absolute value while maintaining a constant ratio of response units to reinforcer units.

Procedural Translation

The incorporation of continuous response and consequent-stimulus dimensions into the traditional ratio relation introduces some procedural issues that are not usually considered within ratio schedules. Figure 18 illustrates the relation of events under the four possible schedule contingencies incorporating duration and count as response and consequent-stimulus dimensions using an arbitrary ratio relation of 5:1. The traces are labeled as R and S corresponding to the response and the consequent stimulus, respectively, and follow the same conventions as Figure 5. Responses and seconds of response duration are numbered in their ordinal position as they cumulate towards meeting the response criterion. Responses and seconds of response duration that do not contribute to meeting the criterion are not labeled.

The contingencies diagramed in Figure 18 are logical possibilities only; reexamination of these contingencies reveals that the two relations incorporating consequent-stimulus duration are actually identical to the Count-Count and Duration-Count contingencies respectively, and will not be pursued further.

FIXED-RATIO SCHEDULES

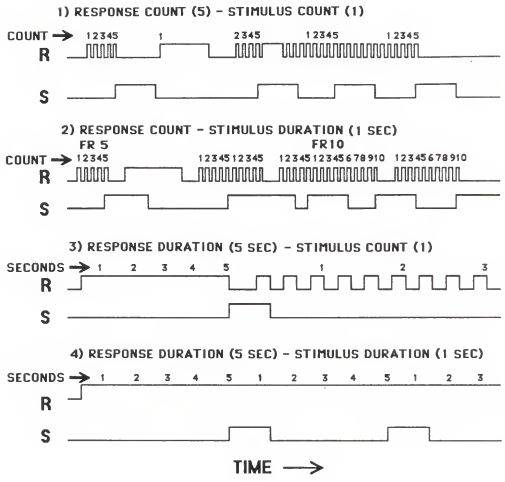


Figure 18. Representation of the four ratio relations incorporating response and/or reinforcing-stimulus duration. Panel 1 shows the Count-Count contingency. Panel 2 shows the Count-Duration contingency under FR 5 and FR 10 to illustrate the effect of longer ratio requirements. Panel 3 shows the Duration-Count relation showing a single long duration response followed by higher rate-lower duration responding. Panel 4 shows the Duration-Duration relation and a single long duration response.
Note: R=response, S=stimulus projector.

Experiment 5: Response Count Related to Reinforcer Count

Introduction

The same strategy as employed previously for interval schedules is used for ratio schedules. The relation of response count and consequent-stimulus count is the traditional fixed ratio contingency; it is used here to evaluate performance engendered by the present procedures against the general literature of fixed ratio performance with animal and human subjects, and to provide a standard for comparing the results of Experiment 6.

Method

Subjects. Five subjects participated in Experiment 5. They were recruited as described under the General Methods section. All subjects were asked prior to starting the first session of the last day if they would participate in additional sessions for payment. Subject RCC1 agreed to serve for four additional hours but only served for two additional hours. She was paid five dollars per hour of participation following each session (all sessions under FR 60 and FR 120). All features of the procedure were identical to sessions for course credit only.

Apparatus. The same apparatus used in Experiments 1,2,3,& 4 was used.

Procedure. Table 7 gives the ratio values and the number of sessions under each value for each subject. With one exception, all subjects were exposed to an ascending series of values. For the

exception, subject RCC3, the ratio requirement was reduced to FR 10 following a single session at FR 60. After shaping, the FR requirement was increased by one up to FR 5 by allowing the subject to obtain at least five reinforcers at each value. Further increases were made if performance seemed adequately maintained. Subsequent increases in the ratio requirement were implemented in a single step.

The duration of the consequent stimulus was ten seconds for the first two subjects exposed to this schedule, and the duration was 30 seconds for subsequent subjects (see Table 7) because of difficulties maintaining responding under the contingencies at large ratio values. Consequent-stimulus durations of 30 s allowed the subjects to read the entire passage in a single, relatively short session removing the necessity to terminate the session at an arbitrary place and disrupt reading of the passage. The use of longer consequent-stimulus durations also equated the total amount of reinforcement across ratio values. The right column of Table 7 gives the duration that the stimulus projector was illuminated for these subjects (10 or 30 s). Sessions generally lasted for one entire reading passage, but occasionally, the final session on a given day was shortened due to time constraints. The average session length was 17.00 min. (range 35.2 to 6.2 min.).

Results

Cumulative response initiation and response duration records are presented in Figure 19. Records were produced in the same manner as in Figure 5. RCC1 initiated responses at high rates at all ratio values, and rates increased with increased ratio values. Response

Table 7

Summary of Experimental Conditions for Subjects under the Fixed-Ratio Count-Count Schedule.

Subject	Ratio Requirement (responses)				Consequent Stimulus Duration (sec)
	10	30	60	120	
RCC1	-	10	5	2	30
RCC2	-	7	-	-	10
RCC3	5[2]	-	1	-	30
RCC4	4	5	-	-	10
RCC5	8	-	-	-	30

Note: Numbers indicate the number of sessions that the subject was exposed to under each ratio requirement. Bracketed numbers are second determination sessions following sessions at higher ratio requirements, and dashes indicate that the subject was not exposed to the indicated ratio value.

duration accumulated rapidly as a result of the high rate of very short duration responses. Brief pauses in responding were evident in the count and duration records from FR 30 but were less evident in the records from FR 60 and FR 120.

The records from subjects RCC5 and RCC4 under FR 10 also indicated a high rate of response initiations and short response durations. Short but distinct pauses are evident in the count and duration records. Pauses were followed by high rate response initiations until the consequent stimulus was produced. Responding ceased during the consequent stimulus periods. Under FR 30 the rate of response initiations was less consistent but somewhat higher overall, and the pause-respond pattern is less distinct than under FR 10. Overall response initiation rates were high, and individual response durations were low.

The record from RCC2 under FR 30 showed a somewhat atypical pattern in that response initiations continued at a high steady rate throughout the entire session, including the consequent-stimulus presentation period (the cumulative recorder motor was operated during consequent-stimulus periods for this subject because he continued to respond during the consequent stimulus while the other subjects did not). Only one ratio included a pause-respond pattern (the second ratio), however, as indicated by the duration record this pause in initiating responses was due to continuous responding not to cessation of responding.

Records from subject RCC3 are similar to those from subjects RCC1 and RCC4 under FR 10, although the pauses following consequent-

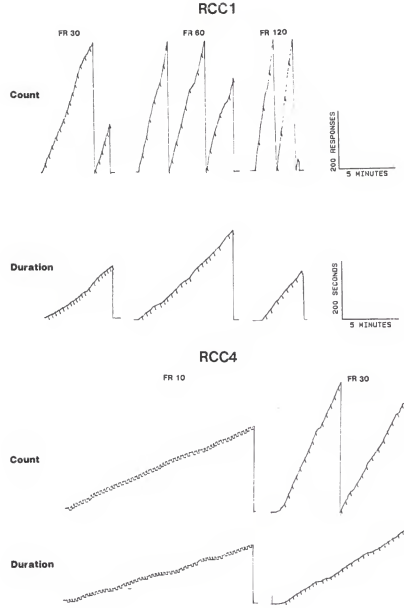


Figure 19. Cumulative records of response count (tracings labeled "COUNT") and cumulative response duration (tracings labeled "DURATION") for all subjects under the fixed-ratio Count-Count schedule. Records are from the last session under each ratio value. The recording pen moved up once for each response initiated (Count record) or for every second of response duration (Duration record). Downward deflections indicate consequent-stimulus presentations. Consequent-stimulus durations were: 30 s for subjects RCC1, RCC3, and RCC5; and 10 s for subjects RCC2 and RCC4. The recorder motor operated during the consequent-stimulus durations for subjects RCC2 and RCC4 under FR 30 and FR 10 respectively.

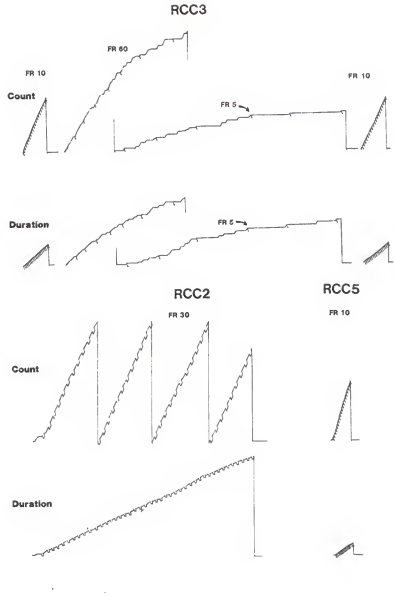


Figure 19 -- Continued.

stimulus presentations were less pronounced. The ratio value was increased directly to 60 from FR 10 for this subject. The overall rate of response initiations decreased throughout the session, and pauses within the ratio became prevalent; response initiations were emitted in "bursts" followed by pauses of increasing length. The ratio value was decreased to FR 5, but long pauses persisted to the end of the session. The performance on subsequent sessions at FR 10 resembled the initial performance under FR 10.

Figure 20 presents the response rate, mean response duration, and the percent of the session spent responding (excluding reinforcement periods) for each session under each ratio value for each subject. Response rates generally increased with larger ratio requirements, but they also tended to increase with longer exposure to constant ratio requirements (eg. subject RCC5 at FR 10 and subject RCC1 at FR 30 and FR 60). The three measures did not co-vary consistently within or across subjects.

Table 8 presents the values of several measures taken from the last session at each ratio value for all subjects. Response rates generally increased with ratio values both within and across subjects (except subject RCC3). The mean post-reinforcement pauses and response durations were very short and changed little across ratio values, and the percent of the interstimulus period spent responding varies unsystematically. Subject ICC1 showed increased interstimulus intervals from FR 30 to FR 60 but this measure changed little from FR 60 to FR 120. Note the number or responses per reinforcer includes the consequent-stimulus periods.

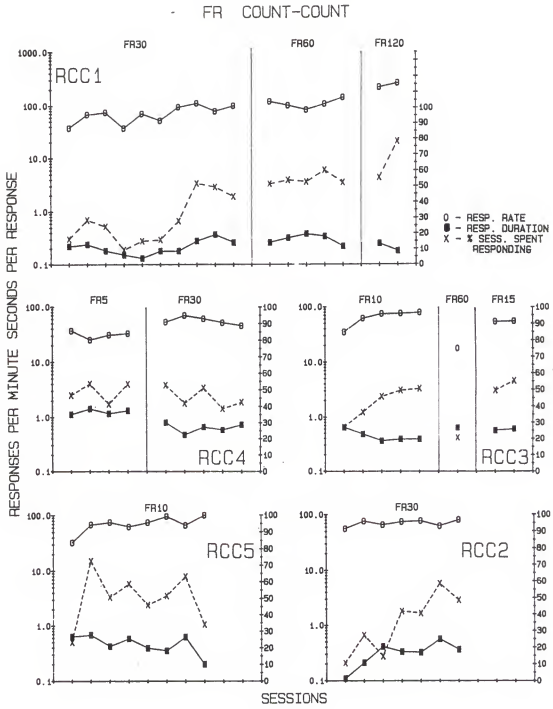


Figure 20. Session means for the FR Count-Count schedule.

TABLE 8
Performance measures under the FR Count-Count Schedule.

Subject & FR Value	Local Rate (R/Min)	Mean Response Duration (Sec/R)	Mean PRP. (Sec)	% IRI Spent Resp.	% Run Spent Resp.	Responses Per Reinforcer	Response Duration Reinforcer	Response Duration Run	Mean IRI (Sec)	% Session In Stimulus
RCC1-30	98.0	0.3	2.9	43.2	57.7	30.8	9.0	8.0	18.5	61.2
60	140.9	0.2	2.0	52.3	65.0	61.0	15.4	13.4	25.6	52.8
120	263.7	0.2	1.8	78.0	87.8	121.9	21.8	21.3	24.7	52.4
RCC2-30	80.2	0.4	0.4	48.5	49.7	39.5	18.2	9.1	18.8	34.7
RCC3-10	79.5	0.4	1.5	50.8	64.1	10.2	3.7	3.8	7.2	79.9
60	17.6	0.6	56.0	20.5	32.1	45.5	31.7	28.5	154.8	16.1
15	55.1	0.7	2.7	62.7	66.3	15.0	10.2	9.0	16.3	64.8
RCC4-10	33.2	1.0	1.5	53.4	61.7	5.8	4.9	9.9	9.8	49.3
30	70.3	0.4	1.4	41.8	74.1	30.6	10.8	10.7	25.6	28.0
RCC5-10	99.5	0.2	2.0	34.0	51.3	10.8	2.1	2.1	6.0	82.5

Discussion

The patterns of response initiation were dissimilar in several respects to the patterns of fixed ratio responding typically displayed by non-human subjects (Ferster & Skinner, 1957; Powell, 1968) and sometimes by human subjects (e.g., Long, 1962; Gonzalez & Waller, 1974). The most obvious difference is the absence of substantial post-reinforcement pauses which should be more noticeable at larger ratio values (Powell, 1968; Felton & Lyon, 1966). Instead, pauses became less noticeable at higher response requirements. The absence of post-reinforcement pauses under ratio schedules is not atypical for performances by human subjects under fixed ratio schedules (e.g., Sanders, 1969; Weiner, 1969; Lowe, 1979). The increase in response rate with increased ratio requirements and the tendency for the interreinforcement interval to remain constant (i.e., subject RCC1) is also not a consistent finding with animal subjects (Felton & Lyon, 1966; Powell, 1969). The negative relation between pause length and inter-reinforcement time may have differentially reinforced short pauses because the textual reinforcing stimuli were not independent of each other in terms of reinforcing value but were related sequentially.

The responding of RCC3 at FR 60 appears to be a classic example of "ratio strain" observed with non-human subjects (Ferster & Skinner, 1957). Pauses developed in the "run" and became more frequent and longer, while response bursts became less frequent and shorter. Responding recovered quickly on the subsequent session with a new reading passage under FR 10, but not within the session even

when the ratio was reduced to FR 5. It may be that the material from that passage had lost its reinforcing efficacy due to the disruption in the continuity of the passage and would no longer support behavior even under short ratio values.

A feature worth noting here is that the ratio strain or change in performance displayed by subject RCC3 is inconsistent with an interpretation of rule-governed responding. Rule-governed responding reportedly produces performances that persist unchanged despite changes in the contingencies or conditions of reinforcement (Baron, Kaufman, & Stauber, 1969; Kaufman, Baron, & Kopp, 1966; Matthews, Shimoff, Catania, & Sagvolden, 1977). The performance of RCC2 is typical of the high steady rates of responding characteristic of rule-governed "ratio" performance (Lowe, 1979).

Experiment 6: Response Duration Related to Reinforcer Count

Introduction

Rider and Kametani (1984; 1987) described modified ratio schedules in which a reinforcer was delivered following the accumulation of a specified duration of lever holding in rats. The obtained patterns of lever holding were analogous to fixed ratio and variable ratio performances under schedules of discrete responses. Reinforcements were followed by pauses, and then by long duration lever pressing or holding until the next reinforcer delivery. The length of the post-reinforcement pause was positively related to the hold requirement. The schedules used in experiment 6 were similar to those used by Rider and Kametani, except that the response in the

present study required continuous movement rather than the static response of holding a lever down. The schedule allowed one consequent-stimulus presentation of fixed duration for each completion of the cumulative response duration requirement.

The results of Experiment 5 indicated that the reinforcement procedure would probably produce patterns disparate from those obtained by Rider and Kametani in that a pause and run pattern might not be expected. Performance should be analogous to performance under the Count-Count schedule in experiment 5 but with respect to response duration. That is, response duration should be long and response rate should be low; the inter-reinforcement time should be taken up with continuous responding.

Methods

Subjects. Four subjects participated in experiment 6. They were recruited as described under the general methods section. Before the start of the first session of the last day of scheduled participation, subjects were asked if they would participate in additional sessions for payment. Subject RDC1 agreed to serve for two additional hours. She was paid five dollars per hour of participation in the last three sessions under FR 30 and all sessions under FR 60. All features of the procedure were identical to sessions for course credit only.

Apparatus. The same apparatus used in Experiments 1, 2, 3, 4,& 5 was used.

Procedure. Table 9 gives the ratio values and the number of sessions under each value for each subject. All subjects were exposed to an ascending series of values. Procedures for shaping and

Table 9

Summary of Experimental Conditions Under the Fixed-Ratio Duration-Count Schedule.

Subject	Ratio Requirement (sec)				Consequent Stimulus Duration (sec)
	5	10	30	60	
RDC1	-	7	6	2	30
RDC3	-	5	3	-	10
RDC4	4	2	-	-	10
RDC5	-	-	7	-	30

Note: Numbers indicate the number of sessions under each ratio requirement. Dashes indicate that the subject was not exposed to that ratio value.

increasing the ratio value were the same as described for Experiment 5. All other procedures for subject selection, instructions, and conduct of the sessions were identical to the previously described experiments.

The right column of Table 9 gives the duration that the stimulus projector was illuminated for these subjects (10 or 30 s). The consequent-stimulus duration and the FR requirement were initially 1 s. Both were increased in one second increments up to FR 5, then the duration of the consequent stimulus was increased to the final value and held constant for all subsequent sessions. The duration of the consequent stimulus was assigned when the subject was assigned to the schedule contingency and not on the basis of performance. Sessions lasted for one complete reading passage. The final session for subjects RDC1 and RDC3 were terminated before the end of the passage due to time constraints.

The pulses from the recycling timer that was used to measure response durations operated a predetermining counter that operated the stimulus projector after the requisite number of seconds had been counted. This contingency is represented schematically in the second panel of Figure 18. The consequent stimulus could be produced only by accumulating the requisite amount of response duration; all of the time that the wheel was in motion counted towards the criterion regardless of the number of response initiations.

Results

Cumulative records of response initiations (counts) and response duration from the last session under each ratio value for each subject

are presented in Figure 21. Records were produced as described previously, the cumulative recorder motor operated during the consequent-stimulus period for subjects RDC3 and RDC4, but not for RDC1 and RDC5.

Three of four subjects accumulated duration at steady rates, stopped responding during the consequent stimulus, and resumed responding immediately following the consequent stimulus. Records from Subject sometimes RDC4 showed a pause-respond pattern in the duration record at FR 5 and 10, and the interstimulus times varied from ratio to ratio. The pauses and interstimulus times for this subject were quite long during the initial sessions and scores on the comprehension tests were at chance levels; the ratio value was held at FR 5 for four sessions until responding became more consistent. This subject dropped out of the experiment before he could be exposed to larger duration requirements.

Records of response count for all subjects showed that the number of responses initiated per consequent stimulus was variable; some ratios contained many responses and some only a single, long duration response. Frequently, the rate of responding increased at the end of the inter-reinforcer interval following an initial period of low rate responding. Despite variations in response rate, only subject RDC4 showed substantial variability in the rate at which duration accumulated. There was little difference in the records from RDC3 with 10 s consequent-stimulus events and RDC5 and RDC1 who received 30 s consequent-stimulus presentations. Note that the number of

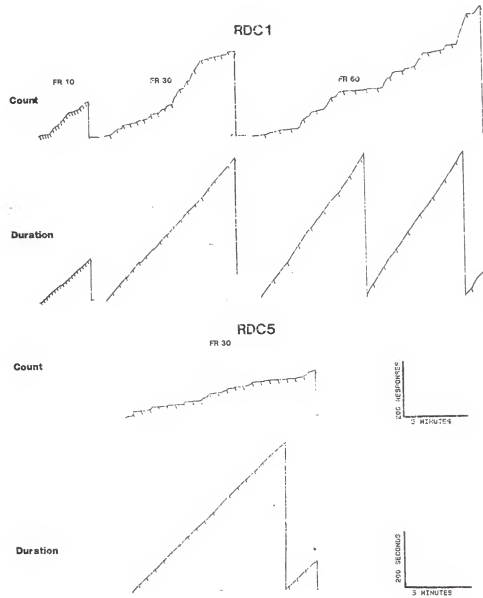


Figure 21. Cumulative records of response count (tracings labeled "COUNT") and cumulative response duration (tracings labeled "DURATION") for all subjects under the fixed-ratio Duration-Count schedule. Records are from the last session under each ratio value. The recording pen moved up once for each response initiated (Count record) or for every second of response duration (Duration record). Downward deflections indicate consequent-stimulus presentations. Consequent-stimuli were 30 s long for subjects RDC1 and RDC3, and 10 s long for subjects RDC3 and RDC4. The recorder motor continued to operate during the stimulus for subjects RDC3 and RDC4.

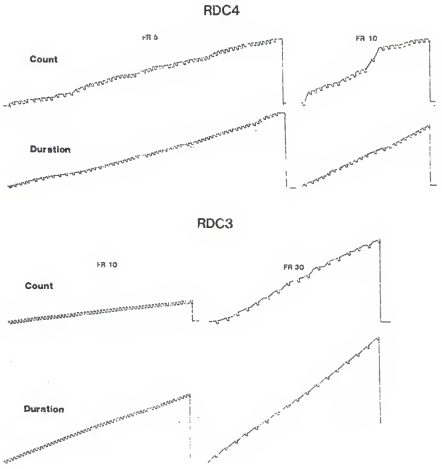


Figure 21 -- Continued.

responses was lower and the slope of the duration record was slightly steeper for subject RDC1 under FR 60 than under FR 30.

Figure 22 presents data from each session under each ratio value for all subjects. Within phases response rates and durations were variable. The percent of the interstimulus time spent responding generally increased with the ratio requirement and also within phases. This measure was low for subject RDC4. For subject RDC1, response duration was stable under FR 30 and increased at FR 60. Duration increased across sessions at FR 30 for subject RDC5, but decreased across sessions at the same ratio requirement for subject RDC3. Response rate and durations were generally negatively correlated, but the percent of the interstimulus interval spent responding was not directly related to these measures. Table 10 presents values for these and additional measures from the last session under each ratio requirement. Post-reinforcement pauses were very brief and did not increase with the ratio requirement for three of four subjects. Substantial post-reinforcement pauses were observed in only one subject under short ratio requirements. The number of responses per consequent-stimulus presentation increased with the cumulative duration requirement for all subjects except subject RDC1 at the longest requirement of FR 60. The length of the average interstimulus interval was greater than the value of the cumulative duration requirement for all subjects and this difference was not due solely to the length of the post-reinforcement pause.

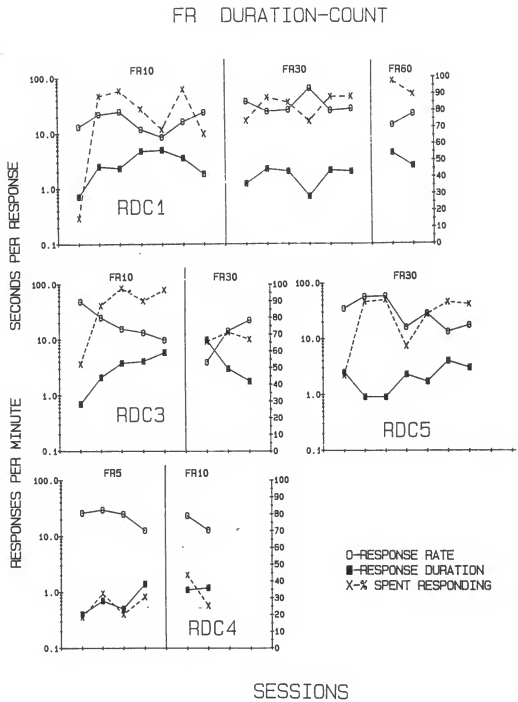


Figure 22. Session means for the FR Duration-Count schedule.

TABLE 10
Performance Measures under the FR Duration-Count Schedule

Subject	FR	Local Rate (R/Min)	Mean Response Duration (Sec/R)	Mean PRP. (Sec)	% IRI Spent Responding	*Responses Per Reinforcer	Resp. Per Run	Mean IRI (Sec)	% Session In Stimulus
RDC1	10	23.4	1.7	1.0	65.9	6.3	5.9	15.1	66.4
	30	24.2	2.2	1.2	80.1	15.3	14.3	36.0	43.5
	60	21.8	2.5	1.5	89.6	24.6	24.3	66.9	30.5
RDC3	10	9.0	5.9	1.2	88.0	1.8	1.7	11.3	38.8
	30	22.4	1.8	1.2	90.2	17.6	16.8	33.2	18.9
RDC4	10	17.1	1.4	6.9	41.0	9.9	3.4	12.2	44.9
	30	31.1	1.2	3.5	60.8	10.0	8.5	16.5	39.7
RDC5	30	17.6	3.0	2.0	88.1	10.5	10.0	34.0	46.7

Performance measures from the last session of each interval value for all subjects under the FR Duration-Count Schedule.
*Includes responses emitted during reinforcement period.

Discussion

Response durations and the percent of the inter-reinforcement interval spent responding were higher under the present fixed-ratio schedule relating duration to consequent-stimulus count than under the Count-Count schedule in Experiment 5. At the longest ratio value (FR 60) response durations became longer, response rate lower, and the percentage of the session spent responding greater than for lower requirements. Response rate was variable under the Duration-Count schedule and many ratios displayed increased numbers of responses late in the inter reinforcement interval. Longer duration responses tended to occur early in the inter-reinforcement-interval, producing a pattern that was the reverse of a pause-respond pattern with respect to the duration of individual responses.

Performances were analogous to those obtained under the FR Count-Count schedule but with respect to duration. Subject RCC1's rate increased and durations decreased with larger response requirements; subject RDC1's response durations and percent of the interreinforcement interval spent responding increased and rate decreased at the largest duration requirement. Responding at FR 30 was not at maximal levels for any subject under either schedule. Subjects were not tuning the wheel continuously once responding started after the termination of the consequent stimulus. This is analogous to the performance observed under FR 30 in experiment 5 in which less than maximal rates were obtained. The fact that response durations increased and the number of responses emitted decreased for subject RDC1 at FR 60 indicates that performance at FR 30 was not at

maximal levels and that longer duration requirements may increase performance by increasing duration and the percentage of the run spent responding.

The effect of consequent-stimulus length was not large, as the performance of subject RDC3 at FR 30 was nearly identical to that of RDC1 and RDC5 at FR 30. However, across sessions, response durations decreased and response count increased for the short reinforcer duration subjects, but not for the subjects receiving 30 s consequent stimuli. The increase in the length of the consequent stimulus was made for practical reasons, rather than as a controlled assessment of reinforcement magnitude. The 10 s consequent stimulus may have been too short to be an effective reinforcer under these ratio schedules (but not the interval schedules), as indicated by the attrition rate and performance of subject RDC4 and possibly RDC3. Three subjects (two in Experiment 6 and one in Experiment 5) did not return after the first one-hour session and two subjects (RDC4, and RCC2) failed to return after two hours of participation (failure to attend an experimental session without notice resulted in loss of credit for one hour already accrued). Scores on the comprehension tests were as a group lower for the fixed ratio subjects and lowest for subjects with 10 s consequent-stimulus presentations; RDC4 scored at chance levels, and scores for RDC3 dropped from an average of 80% correct under FR 10 to 50% correct under FR 30.

Ratio performances under the present procedures did not produce consistent post-reinforcement pausing as observed by Rider and Kametani (1984; 1987) using lever holding with rats as subjects. The

present study used a response that required continuous motion rather than a static response, but the absence of pausing may be related more to the sequential nature of the reinforcer used, as discussed in Experiment 5. Other aspects of performance obtained under the present contingencies are similar to those obtained by Rider and Kametani (1984; 1987), however. In both studies by Rider and Kametani (1984; 1987), under fixed hold requirements of 30 s, many responses were initiated. The rats in The Rider and Kametani (1987) study emitted on average between 3 to 35 (mean of 8.82) responses per reinforcer, the range of mean inter reinforcement times from the 1984 study was 38 to 134 s and the percent of the inter-reinforcement-interval spent responding ranged from 22 to 97%. These values are comparable to those obtained in the present study.

PART 4
GENERAL DISCUSSION

Comparison of Schedule Effects

Six experiments were conducted to illustrate the effects of intermittent schedules that incorporated the continuous dimensional quantity of duration in the formal definition of the response and/or the reinforcing stimulus. Comparison of the performances generated under these schedules with similar schedules involving the dimensional quantities of response and reinforcement count will allow assessment of the relative contributions of continuous and discontinuous response and consequent-stimulus dimensions.

The following sections will describe differences and similarities across the six schedules studied, and relate these to the nature of the response and consequent-stimulus dimensional quantities incorporated into the contingencies. For ease of explication, this discussion will focus on measures of duration and rate. These provide the minimum data necessary for comparing the effect of each schedule. In spite of individual differences in absolute rates and durations, clearly different patterns of responding were evident in cumulative records and summary data as a function of the nature of the response and consequent-stimulus dimension that served as the formally relevant response dimensions.

Effect of Discontinuous Response and Reinforcement Dimensions: Count-Count Schedules

The Count-Count schedules related response and reinforcing-stimulus elements in terms of their countability--one response was counted each time wheel turning was initiated--and were intended as a systematic replication of traditional interval and ratio schedules. To the extent that the Count-Count schedules generated patterns of responding that are reasonably comparable to those generated by more typical fixed-interval and fixed-ratio procedures, the Count-Count schedules provide the basis for generalizing the present findings to the existing schedule literature.

The Count-Count schedules generally reproduced performances characteristic of fixed-interval and ratio schedules. The FI Count-Count contingency generally produced temporal patterning and interval-to-interval variations resembling second order deviations in response rate characteristic of performances under fixed-interval schedules (although they show many signs of performances usually seen early in training under typical procedures). The fixed-ratio schedule contingency produced high steady rates of responding, as is typical for fixed-ratio schedules. Response rates were higher and response durations were shorter under this contingency than for any of the other five in the present series of experiments. Furthermore, the typical indications of ratio strain--responding in bursts and pauses of increasing length--were displayed by the subject (RCC3) who was exposed to conditions expected to produce strain. However, unlike typical performance with non-human subjects, post-reinforcement pauses under the ratio schedule were consistently short and did not increase

with increases in the response requirement. High constant rate responding with little or no post-reinforcement pausing is frequently observed in human performance under fixed-ratio schedules (Holland, 1958; Weiner, 1964a; 1964b; See Lowe, 1979 for a review).

Duration records under both fixed-interval and fixed-ratio Count-Count schedule contingencies often mirrored the patterns of response initiation in that duration accumulated as a function of response occurrences (and not as a function of prolonged wheel turning). Response durations were longer under the fixed-interval schedule, averaging 1.2 s, 2.3 s, and 1.0 s at FI 10, 20-25, and 30-35, respectively, and .52 s and .31 s at FR 10 and 30, respectively. Average response duration was more variable across sessions and subjects under the FI schedule than under the ratio schedule.

These FI performances generally conform to results from studies that have measured response duration (usually lever holding) under fixed-interval schedules of discrete responses (e.g., Antonitis, 1951; Herrick, 1964; Herrick & Bromberger, 1965; Margulies, 1961; Millenson, Hurwitz, & Nixon, 1961; Stevenson & Clayton, 1970; see Fowler, 1987 for a review). Under fixed-interval schedules of response count containing no programmed differential reinforcement for duration, duration typically decreases and rate increases with exposure to the schedule, but response durations remain longer under interval than ratio schedules (Stevenson & Clayton, 1970). Changes in the interval value or schedule contingencies usually increase response duration temporarily (Schaefer & Steinhorst, 1959; Millenson, Hurwitz, & Nixon, 1961; Stevenson & Clayton, 1970). Thus, duration varied under the

present Count-Count schedules as it does under standard procedures when duration is measured as an adjunct to rate.

Effect of Continuous Response Dimensions: Duration-Count Schedules

The effects of incorporating the continuous response dimensional quantity of duration into interval and ratio schedule contingencies may be explored by comparing response rates and durations under FI and FR Duration-Count schedules to these same measures under FI and FR Count-Count schedules. Under the Duration-Count schedule contingencies, reinforcement was solely dependent on the duration of responding, whereas under The Count-Count schedules, it depended on the simple occurrence or count of responses; all other aspects of the schedules were formally identical. There were no differential reinforcement contingencies requiring a response of a specific criterion duration or an additional response initiation or termination requirement. It should be noted however, that there were some functional differences of potential importance. The Duration-Count schedules introduced a potential delay between the onset of the response and the delivery of reinforcement, whereas the Count-Count schedules did not. Also, the duration schedules did not require response termination. These differences are inherent in the way that quantities were incorporated into schedule contingencies and may have their own effects; this must be analyzed by further research.

Fixed-interval schedules. The FI Duration-Count schedule produced very different response rates and response durations than the FI Count-Count schedule. Under the FI Duration-Count schedule, rates were very low for all subjects; often one or fewer responses was

initiated per interval. Responses were initiated early in the interreinforcement interval (except for one subject who generally emitted one, one-second response at the end of the interval). Rather than emitting a large number of short duration responses as under the FI Count-Count schedule (mean duration of 1.18 s, 2.03 s, & 1.02 s under FI 10, 20-25 s, & 30-35 s respectively), very few responses of quite long duration occurred (mean duration of 24 s, 65 s, & 14.4 s under FI 10, 25, & 35 s respectively). Note the mean durations under the FI Duration-Count schedule were sometimes longer than the interval value because a response initiated in one interval continued across several intervals.

A characteristic of fixed-interval schedules is that the rate of reinforcement remains relatively invariant over a wide range of response rates and durations. Thus, in the present studies, duration was free to vary under the Duration-Count schedule in the same manner that rate was under the Count-Count schedule. The result was that duration displayed dynamic properties under the Duration-Count schedule similar to those shown in rate under the Count-Count Schedule contingency. Thus these two FI schedules affected the formally relevant dimensions in similar ways.

The FI Count-Count and FI Duration-Count schedules differed in their effects on the formally irrelevant dimensions--response duration under the Count-Count schedule and response count under the Duration-Count schedule. Response initiation rates were consistently very low for all subjects under the Duration-Count schedule. However, under the Count-Count schedule response duration varied widely among

subjects, and long-duration responding was produced by at least three of the eight subjects. Thus, three subjects did not show differentiated responding across the interval, and wheel turning in the interval persisted, despite the lack of reinforcement during this time. The latter may be because the manipulandum (a wheel) in combination with the low force requirement encouraged (or did not discourage) unnecessary turning. Azrin (1958) obtained pause-respond patterns from human subjects under FI schedules of button pressing only after increasing the force requirement from 15 gm to "several hundred grams", and other response-cost procedures have been shown to decrease responding during FI schedules (e.g., Weiner, 1962).

Response durations might have been enhanced by the present procedures because the physical attributes of the manipulandum and subject anatomy do not restrict duration, as is the case of a pigeon pecking a key (Fowler, 1987) or the use of manipulanda that allow limited movement such as lever or button pressing (Williams, 1985). However, characteristics of the manipulandum did not preclude short duration responding and force long duration responses, as evidenced by the shorter response durations emitted by four of the eight subjects under the FI Count-Count schedule and the very short duration responses emitted by all subjects under the FR Count-Count schedule (in which duration was also formally irrelevant). Thus, an interaction between the type of schedule and the type of dimensional quantity produced the difference in the formally irrelevant dimensions as well as the relevant dimensions. That is, the interval schedule tended to enhance (or permit relatively greater amounts of) response

duration, but not the rate of response initiations when these dimensions were formally irrelevant for reinforcement, while the comparable ratio schedule did not.

The apparent tendency for the FI schedule to enhance the irrelevant dimension when that dimension was duration but not when it was count may be related to the tendency of interval schedules to reinforce relatively long IRT's (i.e., IRT's that are longer than those under comparable ratio schedules, e.g., Ferster & Skinner, 1957; Morse, 1966; Dews, 1970). Response duration is part of the IRT and might be expected to be affected similarly to other interim behaviors during the time between response initiations. The probability of reinforcement for initiating a response following a relatively long duration response is similar to the probability of reinforcement for initiating a response terminating a long period of not responding during the IRT. The tendency to fill this time with continuous responding might be enhanced by the physical attributes of the manipulandum, which was purposely designed to not restrict response duration relative to pigeon's key pecks and lever or button pushing with rats and humans (Williams, 1985). The FI Count-Count schedule was not highly selective of the intervening response initiations allowing variation in duration or non-responding time, and about half the subjects emitted longer response durations than necessary and about half emitted other behavior. The use of a greater force requirement may have reduced the observed inter-subject variability by suppressing responding (Azrin, 1958). Overall rates of response

initiations were not reliably different between subjects emitting these two performances.

The Duration-Count schedule appeared to increase selectively response duration and decrease rate of response initiations. The performances of subjects IDC1 & IDC4 are especially noteworthy in this regard because they show temporal patterning in the distribution of response duration across the interval. Rates of response initiations were universally low under this schedule, indicating a specific selective process for the production of uninterrupted responding. In light of the discussion of IRT above, it should be noted that under fixed-interval reinforcement of response duration, the interim behavior of wheel turning is also the dimension of responding that contacts reinforcement. Under FI Count-Count schedules, the interim behavior and terminal behaviors are incompatible.

Fixed-ratio schedules. The two fixed-ratio schedule contingencies (FR Count-Count and FR Duration-Count) produced quite different performances with respect to response count and response duration, but similarities were still evident. Under both schedules, cumulative records of the relevant dimensional quantity showed accumulation at high steady rates. The post-reinforcement pauses were short and generally decreased with increased response requirements under both contingencies.

The two schedule contingencies differed with respect to the levels of the formally irrelevant dimensional quantity maintained (duration under FR Count-Count and rate under FR Duration-Count). Whereas the Count-Count schedule consistently produced very short

response durations, the Duration-Count schedule did not produce low response initiation rates. Response rate under the Duration-Count schedule was lower than under the Count-Count schedule, but it was not at the minimum of one response per reinforcer, and initiation rate was variable within and across ratios. As with the interval schedules, there was an interaction between the type of schedule and the levels and variability shown in measures of the dimensional quantity formally irrelevant to reinforcement. However, the ratio schedule contingency enhanced the discontinuous dimensional quantity of count.

Interval compared with ratio schedules. Thus far, we have compared performance on schedules involving response duration with performance on schedules involving response count within a particular type of schedule (FI or FR). The interaction of the nature of the response element and the nature of the relational element (schedule contingency) can be assessed by making comparisons between FI and FR schedules. When response count was related to consequent-stimulus count, the fixed-ratio schedule consistently produced high rate, very short duration responding, while the FI schedule produced moderate rate, and moderate to low (and variable) response durations. There was also a tendency to respond continuously, in stead of making discrete responses under the interval schedule. Overall, differences in performances were generally congruent with the literature using more traditional procedures (e.g., Ferster & Skinner 1957). One exception is the greater post-reinforcement pausing under the FI schedule than under the FR schedule.

In considering the differences between the FI and FR Duration-Count schedules, it should be remembered that there were no additional criteria for differential reinforcement of specific individual response durations. Rather, the reinforcement criterion specified the minimum cumulative duration of responding necessary for reinforcement with no specification of the number (beyond one) of responses emitted. These contingencies could be contacted in a variety of different ways. The resultant performances reflect the particular selection properties inherent in ratio- and interval-based contingencies. Despite the greater fixed response duration requirements under the FR Duration-Count schedule (5, 10, 30, or 60) compared to the FI Duration-Count schedule (one second), individual responses were shorter in duration under the FR than under the FI Duration-Count schedule. The latter produced relatively few response initiations (and terminations) and longer average response durations.

These results are in accordance with results of a similar comparison of fixed-ratio and fixed-interval schedule contingencies of continuous response dimensions by Notterman and Mintz (1965). This study used fixed-interval and fixed-ratio schedules of response effort, rats as subjects, and a fixed bar containing a force transducer as the manipulandum. Response effort was defined as the time integral of force of individual responses, and was measured in units of gram-seconds. Unlike the present relations, reinforcement was delivered on response termination. Under the fixed-interval schedule, the first response that terminated after the interval had expired and that met the criterion effort requirement produced food

/reinforcement. The ratio schedule was a fixed cumulative effort schedule in which reinforcement was delivered following termination of responding after the required amount of effort had accumulated. The interval schedule produced individual responses with relatively consistent amounts of effort, and the amount of effort per response was distributed around the criterion for reinforcement. The responses were emitted in a pause-respond pattern. The ratio schedule also produced responses in a pause respond pattern. Analogously to duration in the present ratio schedules, the average effort per response was generally less than obtained under the interval schedule, and the number of responses per ratio was variable.

Effect of Continuous Reinforcement Dimensions: FI Count-Duration and FI Duration-Duration Schedules

The effects of modifying the traditional fixed-interval schedule contingency to incorporate reinforcement duration may be assessed by comparing the Count-Duration and the Duration-Duration schedules and their counterparts, the Count-Count and the Duration-Count schedules (no ratio schedules incorporating consequent-stimulus duration were studied). As with previously discussed schedule contingencies, the fixed-interval schedule incorporating consequent-stimulus duration programmed no specific differential reinforcement contingencies for responding during the interval itself. However, schedules involving response duration did introduce certain procedural differences from those involving response count. Specifically, the former schedules allowed the reinforcing stimulus to be prolonged indefinitely. A break in the continuity of the reinforcing stimulus marked the

beginning of a new interval. This feature changed a basic property of interval schedules--it allowed the interreinforcement interval (when measured from stimulus onset to stimulus onset) to vary radically as a result of responding because the duration of the reinforcing stimulus was related to the level of the response dimension. This also introduced a relation between cessation of responding and cessation of the consequent-stimulus, in essence, an avoidance contingency in which responding at high levels of the relevant dimension postponed termination of the stimulus. The relation of these features to performance will be the focus of discussion.

The Count-Duration schedule produced the highest response rates of all the interval schedules studied. Performance in the last session under the Count-Duration schedule consisted of constant high rate, short duration responding during the interval and reinforcement periods for two subjects and alternating high rate, short duration and lower rate/longer duration responding for the third. Two of the three subjects produced prolonged consequent-stimulus durations, but this performance developed only after extensive exposure to the schedule. Compared to the Count-Count schedule, no subject under the FI Count-Count schedule showed the high constant rate performance shown by the two high rate subjects under the FI Count-Duration schedule.

The low rate and long duration performance under the Duration-Duration contingency was distinctly different from performance under the Count-Count and Count-Duration schedules, and this may be attributed to the difference in the response dimension incorporated. However, the Duration-Duration schedule produced the longest duration

responses of all the interval schedules, and all subjects consistently prolonged the reinforcing stimulus. Long duration responding was consistently maintained during the consequent-stimulus period accounting for 92% to 98% of the total session duration, and this may be attributed to the reinforcement dimension incorporated.

Comparing performances under the Duration-Duration and the Duration-Count schedules holds the effect of the response dimension constant so the effects of the reinforcing-stimulus dimension can be observed. Only one of four subjects (IDC3) exposed to the Duration-Count schedule turned the wheel virtually constantly throughout the session (see Figure 10). This performance was nearly identical to that of all four subjects exposed to the Duration-Duration contingency. The performance of this subject indicated that reinforcement of response duration alone could produce this very long duration pattern. However, the Duration-Count schedule produced a wide range of inter-subject variability in response duration compared to the Duration-Duration schedule contingency (compare Figure 10 with Figure 16). Thus, while the continuous responding pattern shown by all subjects under the Duration-Duration schedule may occur when response duration is reinforced with an invariant reinforcer (Duration-Count), the Duration-Duration relation selected this performance specifically. The extreme values of rate and duration measures, together with the uniformity of performances across subjects, suggests that incorporating reinforcement duration into the contingency increased the selective power of the contingency relative to the other fixed-interval relations incorporating reinforcer count.

This increased selectiveness was less apparent under the Count-Duration schedule. While mean response rates were quite high, only two of the three subjects consistently prolonged the consequent stimulus, and one of these two subjects developed this performance only in the last session of participation. In earlier sessions, this subject frequently prolonged consequent-stimulus periods several times per session, but ceased responding during the reinforcement period (this was followed sometime latter by termination of the consequent stimulus). Remember that one-second of stimulation was provided for each response initiation and high rates of responding would "save up" reinforcement time. This provided a potential variable delay between cessation of responding and cessation of stimulation. Note also that the subject did not have to cease responding altogether to terminate the consequent stimulus--only decrease the rate of responding below one per second.

The present results suggest that a reinforcement contingency that allows responding to produce increases in consequent-stimulus duration more effectively selects long duration responses than it does a high rate of discrete responses. This difference is not due to lack of contact by the subjects' performance with the relation between responding and prolonging the consequent stimulus because all three subjects under the Count-Duration schedule prolonged the consequent stimulus at some point.

Evidently, the increased selective power of relations incorporating consequent-stimulus duration is related to the point-to-point correspondence of consequent-stimulus change and responding.

The correspondence between responding and initiation of the consequent stimulus is equally sharp under both schedules. However, under the Count-Duration schedule, an arbitrary minimal unit of duration was related to the minimal response unit. The relation of one second of stimulation to one nearly instantaneous response reduced the moment-to-moment correspondence between changes in responding and termination of the consequent stimulus.

Fixed-interval schedules have been shown to be relatively insensitive to the effects of relating response count to variation in reinforcement duration. When duration was related to the number of responses emitted under an FI 5 min schedule (Gentry & Marr, 1982) this relation failed to increase response rates. The interaction of such features of scheduling reinforcement availability with the effectiveness of relations between response and consequent-stimulus dimensions deserve further study, and may be significant in the analysis of behavior in natural environments and have practical implications.

Effects of fixed-interval schedules

The performances under the FI Count-Duration and FI Duration-Duration schedules were similar to those obtained in previous work under Count-Count and Duration-Duration schedules of continuous reinforcement (CRF) (Williams, 1985; Williams & Johnston, in press) in that response rates were higher under CRF Count-Duration compared to CRF Count-Count, and response durations and the percentage of the session spent responding were greater under CRF Duration-Duration compared to CRF Duration-Count.

This enhancement in performance may be related to the differences in the consequences of response cessation once the consequent stimulus has been produced under the interval schedule and CRF. Under FI, cessation of responding during the stimulus period not only terminates the consequent stimulus but returns to a period in which reinforcement is not available. Thus avoidance of reentry to the interval period (Thomas, 1966; Findley, 1962) may be enhanced over a CRF contingency in which cessation of responding only terminates the stimulus and instates a period in which reinforcement is available without delays imposed by the interval. This schedule then may function as a chain or tandem schedule with the added contingency of allowing avoidance of entry into the initial link; this is similar to Findley's (1962) single response procedure.

Under the Findley (1962) procedure, pigeons responded on a single manipulandum under a chained FI 120 s, FR 100 with grain reinforcement. In the terminal link two concurrent contingencies were in effect such that food was presented for four seconds after each 100th response and IRT's of six seconds or greater reinstated the initial (FI) link. The six second requirement included the reinforcement period, and after reinforcement, the same conditions remained in effect. Thus, while the duration of the reinforcing stimulus <u>per se</u> was not related to responding, the duration of the component in which reinforcement was available was related to rate of responding. Compared with a phase in which the terminal link could not be prolonged, FR performance was enhanced. Response rates were higher and fewer IRT's or post-reinforcement pauses exceeded six

seconds with the IRT contingency in effect, while without the IRT contingency almost all post-reinforcement pauses exceeded six seconds. Performance in the terminal link was affected by increasing or decreasing the ratio requirement and the length of the IRT required to return to the initial component (FI). Increasing the ratio requirement disrupted ratio performance and increased the frequency of reinstating the initial link (i.e., subjects did not prolong the terminal link as much). However, decreasing the critical IRT duration enhanced responding in the ratio schedule, even though at very short values the animals reentered the initial link after each reinforcer. When the length of the FI in the initial link was manipulated, performance under the terminal FR schedule was better (higher rates and shorter pauses), and subjects prolonged the terminal link longer (fewer reentries to the initial link) with longer FI values. Similar results were obtained when a fixed duration period of S-delta, or a ratio schedule were substituted for the initial link. Thus, performance is partly determined by parameters of the contingencies of the initial conditions and partly by the terminal condition.

The enhancement of performance under FI Count-Duration and Duration-Duration over CRF schedules may be similar to the effects of the initial link conditions on terminal link performance described in Findley (1962; also see Thomas, 1966). However, the present research indicates that contingencies incorporating response duration may follow quantitatively different functions than contingencies incorporating response count. Parametric manipulations of the variables discussed by Findley (1962) and of the contiguity of

response and consequent stimulus initiation and termination will be required to address this issue.

The latter could be accomplished by decreasing the contiguity of response termination and consequent stimulus termination by decreasing the ratio of response duration to consequent-stimulus duration as mentioned in the introduction to ratio contingencies (see part 3). By introducing a ratio of 1:2 under the FI Duration-Duration schedule, one second of responding would produce two seconds of stimulation, and a delay would be introduced between termination of responding and termination of the consequent stimulus. Note, that the same contingency under the Count-Duration schedule would further decrease the point-to point correspondence but would decrease the response rate required to maintain the reinforcer. The effect of this manipulation is unknown. The analysis of these relations as sequences of contingencies (Findly, 1962) seems a fruitful direction in the analysis of naturally occurring behavior in which responding both produces and maintains reinforcement; postponing re-entry to a previous condition.

The enhancing effect of intermittent reinforcement on relations incorporating reinforcement duration may have practical implications. As conjugate reinforcement studies have shown (e.g., Lindsley, 1962), such correlated reinforcement procedures are quite sensitive to the moment-to-moment reinforcement value of the stimulus, and decreases in reinforcement efficacy produce immediate decreases in responding. The avoidance component of fixed-interval schedules may provide a way to maintain high output despite periods of relatively lower reinforcement

value of the consequent stimulus. Longer FI values should produce further increased responding during the stimulus period.

Awareness of these schedule effects might prove beneficial in the analysis of behavior in applied settings. As an example, such intermittent reinforcement might serve to increase undesirable behaviors in a child or an institutionalized retarded individual that might be maintained by attention from a caregiver. The duration of undesirable behavior may control the duration of adult attention (Baer, 1986). Based on the present Duration-Duration schedule results, this may reliably enhance the duration of the undesirable behavior. And the persistance of the response may be related to the length of the previous period of inattention. The reliability of this effect might be contrasted with the variability in duration maintained by discrete consequent stimuli (Duration-Count), such as may be more common for desirable behavior that produces periodic discrete episodes of praise and approval. Intermittent scheduling of opportunity for attention may come about when the caregiver must divide attention across several individuals producing interval-like schedules. Thus, in addition to getting caught in the trap of attending to inappropriate behaviors, caregivers may also be trapped into attending to these behaviors on a more effective schedule than the schedule in effect for desirable behaviors. Analysis of the relative effectiveness of relations like the Duration-Duration schedule and of such concurrent schedules involving different reinforcement and response dimensions may advance the analysis of social relations and other behaviors of practical importance.

Summary and Conclusions

The present series of experiments was undertaken to explore relations of responding and reinforcement that allowed continuous variation in response and reinforcer dimensions under intermittent reinforcement. The endeavor was undertaken to demonstrate the logical and procedural efficacy of incorporating continuous response and consequent stimulus dimensions into schedules typically defined in terms of discontinuous dimensions. To this end, a systematic model was described as a framework for considering comparable relations of continuous and discontinuous response and reinforcer dimensions. Using duration as a representative and fundamental continuous dimension and FI and FR schedules as representative fundamental intermittent schedules, procedural details were chosen on the basis that they allow representation of the basic nature of traditional FI and FR schedules and at the same time, minimally constrain variation in duration.

The results demonstrated that response count and response duration function as similarly reinforceable units under equivalent relations, and showed how subtle differences in behavior-reinforcement interactions can affect performance. Under the present schedules, the sole definer of an effective response was the presentation of the reinforcing stimulus. Different patterns developed as a function of the response dimension upon which reinforcement was based, and these performances were characteristic of the type of schedule when examined in terms of the relevant response dimension. Thus, both response

number and duration fulfilled the requirements for classification as functionally defined operant classes (Skinner, 1935; Catania, 1973), and reinforceable units under FI and FR schedules (Zeiler, 1977). The present demonstration illustrates that duration of responding may follow the same rules of structure and integration as discrete responses (Zeiler, 1986). That is, rate and duration, and other continuous dimensions, are interchangeable both in the definition of formal response classes (i.e., how behavior can interface with the environment) and as direct measures of the reinforcement process (i. e., how behavior does interface with the environment). These contingencies illustrate the processes of response structuring at the molecular level by directly manipulating the features of individual responses that contact environmental change.

A stated goal was to describe procedures that may be more directly analogous to contingencies in non-laboratory settings. The delivery of reinforcement based directly on the cumulative amount of a response dimension (FR Duration-Count), or on ongoing responding periodically sampled (FI Duration-Count), and the enhancement of responding when duration of reinforcement is contingent on performance may be relations routinely found in application (Baer, 1986.). The present work provides a model and procedural examples for an expanded laboratory study of naturally occurring relations that may prove useful in the analysis of basic processes of response structuring and integration.

APPENDIX

Instructions

In general, this is a study of your responding to read and the variables that might affect it. Your task is simply to read the material that may be presented on the screen in front of you as well as you can so please wear your glasses if you need them to read. What you do on the panel below the screen will influence how the material will be presented. The material may be produced one line at a time and you should read each line and try to keep up with the flow of the entire passage. A green light will come on when the material may be read and it will go off when the task is over. At that time you will be asked to complete a short comprehension test. After the task is over you should remain seated until the experimenter comes into the room and tells you what to do next. Remember that what you do while seated at the panel will influence how the material is presented; it is possible to read every line depending on what you do; and you may do anything as long as you remain seated in the chair. If you have any questions you may ask them now.

PLEASE WAIT UNTIL THE GREEN LIGHT COMES ON

Informed Consent Form

This is an experiment on instrumental responding. The purpose of this study is to measure how your responding changes depending on its consequences. In this case, we are interested in how reading material is presented affects reading. You will be asked to read passages of text that are projected onto a screen while making a simple motor response. You will be tested on the material that you read so you will have to pay attention and read carefully. The tests are only to evaluate how well you have read the material and are not intended as an evaluation of how well you can read. At times it will be harder to read the material than at other times depending on the experimental conditions. The nature of this study, requires that you get used to the reading/working situation so we would like you to participate only if you are willing to work for the number of hours stated below. Your participation will be divided into daily sessions.

We do not anticipate that you will experience any discomfort or risk above that experienced in the average classroom. The experimenter will discuss the procedure and rationale of the study in detail as well as answer any questions that you may have about this study or experimentation in general after your period of participation is over.

As stated before, we would like you to participate only if you are willing to work for the total number of hours stated below, but if you agree to participate, you are free to withdraw at any time. If

you have any questions concerning your participation, feel free to ask the experimenter.

I have read and understand the procedures described above. I agree to participate in the procedure and I have received a copy of this description.

I agree to participate for a total of _____ hours.

SIGNATURES:

_____	_____	_____	_____
Subject	Date	Investigator	Date

REFERENCES

Antonitis, J. J. (1951). Response variability in the white rat during conditioning, extinction, and reconditioning. Journal of Experimental Psychology, 42, 273-281.

Azrin, N. H. (1958). Some effects of noise on human behavior. Journal of the Experimental Analysis of Behavior, 1, 183-200.

Baer, D. M. (1986). In application, frequency is not the only estimate of the probability of behavioral units. In T. Thompson & M. D. Zeiler (Eds.), Analysis and integration of behavioral units (pp. 117-136). Hillsdale, NJ: Lawrence Erlbaum Associates.

Baron, A., Kaufman, A., & Stauber, K. A. (1969). Effects of instruction and reinforcement-feedback on human operant behavior maintained by fixed-interval reinforcement. Journal of the Experimental Analysis of Behavior, 12, 701-712.

Bernstein, D. J. (1988). Laboratory lore and research practices in the experimental analysis of behavior: Designing session logistics--how long, how often, and how many? The Behavior Analyst, 11, 51-58.

Branch, M. N., & Gollub, L. R. (1974). A detailed analysis of the effects of d-amphetamine on behavior under fixed-interval schedules. Journal of the Experimental Analysis of Behavior, 21, 519-539.

Buskist, W., Oliveira-Castro, J., & Bennett, R. (1988). Some effects of response-correlated increases in reinforcer magnitude on human behavior. Journal of the Experimental Analysis of Behavior, 49, 87-94.

Catania, A. C. (1963). Concurrent responding: A baseline for the study of reinforcement magnitude. Journal of the Experimental Analysis of Behavior, 6, 299-300.

Catania, A. C. (1970). Reinforcement schedules and psychophysical judgments: A study of some temporal properties of behavior. In W. N. Schoenfeld (Ed.), The theory of reinforcement schedules (pp. 1-41). New York: Appleton-Century-Crofts.

Catania, A. C. (1973). The concept of the operant in the analysis of behavior. Behaviorism, 1, 103-116.

Catania, A. C. (1984). Learning (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Catania, A. C., & Reynolds, G. S. (1968). A quantitative analysis of the responding maintained by interval schedules of reinforcement. Journal of the Experimental Analysis of Behavior, 11, 327-383.

Crespi, L. P. (1944). Amount of reinforcement and level of performance. Psychological Review, 51, 341-357.

Davis, S. F., & North, A. J. (1967). The effect of varied reinforcement training on behavior following incentive reduction. Psychonomic Science, 9, 395-396.

DeCasper, A. J., & Zeiler, M. D. (1977). Time limits for completing fixed ratios: IV. Components of the ratio. Journal of the Experimental Analysis of Behavior, 27, 235-244.

Dews, P. B. (1969). Studies on responding under fixed-interval schedules of reinforcement: The effects on the pattern of responding of changes in requirements at reinforcement. Journal of the Experimental Analysis of Behavior, 12, 191-199.

Dews, P. B. (1970). The theory of fixed-interval responding. In W. N. Schoenfeld (Ed.), The theory of reinforcement schedules (pp. 43-61). New York: Appleton-Century-Crofts.

Eckerman, D. A., Hienz, R. D., Stern, S., & Kowlowitz, V. (1980). Shaping the location of pigeon's peck: Effect of rate and size of shaping steps. Journal of the Experimental Analysis of Behavior, 33, 299-319.

Felton, M., & Lyon, D. O. (1966). The post-reinforcement pause. Journal of the Experimental Analysis of Behavior, 9, 131-134.

Ferster, C. B., & Skinner, B. F. (1957). Schedules of reinforcement. Englewood Cliffs, NJ: Prentice-Hall.

Findley, J. D. (1962). An experimental outline for building and exploring multi-operant behavior repertoires. Journal of the Experimental Analysis of Behavior, 5, 113-166.

Fowler, S. C. (1987). Force and duration of operant responses as dependent variables in behavioral pharmacology. In T. Thompson, P. B. Dews, & J. E. Barrett (Eds.), Neurobehavioral pharmacology: Vol. 6 Advances in behavioral pharmacology (pp. 83-127). Hillsdale, NJ: Lawrence Erlbaum Associates.

Galbicka, G. (1988). Differentiating The Behavior of Organisms. Journal of the Experimental Analysis of Behavior, 50, 343-354.

Galbicka, G., & Platt, J. R. (1986). Parametric manipulation of interresponse time contingency independent of reinforcement rate. Journal of Experimental Psychology: Animal Behavior Processes, 12, 371-380.

Gentry, D. G., & Eskew, R. T. (1984). Graded differential reinforcement: Response-dependent reinforcer amount. Journal of the Experimental Analysis of Behavior, 41, 27-34.

Gentry, D. G., & Marr, M. J. (1982). Intractable properties of responding under a fixed-interval schedule. Journal of the Experimental Analysis of Behavior, 37, 233-241.

Gonzalez, F. A., & Waller, M. B. (1974). Handwriting as an operant. Journal of the Experimental Analysis of Behavior, 21, 165-175.

Harzem, P., Lowe, C. F., & Priddle-Higson, P. J. (1978). Inhibiting function of reinforcement: Magnitude effects on variable-interval schedules. Journal of the Experimental Analysis of Behavior, 30, 1-10.

Hawkes, L., & Shimp, C. P. (1975). Reinforcement of behavioral patterns: Shaping a scallop. Journal of the Experimental Analysis of Behavior, 23, 3-16.

Hendry, D. P. (1962). The effect of correlated amount of reward on performance on a fixed-interval schedule of reinforcement. Journal of Comparative and Physiological Psychology, 55, 387-391.

Hendry, D. P., & Van-Toller, C. (1964). Performance on a fixed-ratio schedule with correlated amount of reward. Journal of the Experimental Analysis of Behavior, 7, 207-209.

Herrick, R. M. (1964). The successive differentiation of a lever displacement response. Journal of the Experimental Analysis of Behavior, 7, 211-215.

Herrick, R. M., & Bromberger, R. A. (1965). Lever displacement under a fixed-ratio schedule and subsequent extinction. Journal of Comparative and Physiological Psychology, 59, 392-398.

Holland, J. G. (1958). Counting by humans on a fixed-ratio schedules of reinforcement. Journal of the Experimental Analysis of Behavior, 1, 179-181.

Holland, J. G., & Skinner, B. F. (1961). The analysis of behavior. New York: McGraw-Hill.

Kaufman, A., Baron, A., & Kopp, R. E. (1966). Some effects of instructions on human operant behavior. Psychonomic Monograph Supplements, 1, 243-250.

Kelleher, R. T. (1966). Chaining and conditioned reinforcement. In W. K. Honig (Ed.), Operant behavior: Areas of research and application (pp. 160-212). Englewood Cliffs, NJ: Prentice-Hall.

Kuch, D. O. (1974). Differentiation of press durations with upper and lower limits on reinforced values. Journal of the Experimental Analysis of Behavior, 22, 275-283.

Lane, H. (1964). Differential reinforcement of vocal duration. Journal of the Experimental Analysis of Behavior, 7, 107-115.

Lindsley, O. R. (1957). Operant behavior during sleep: A measure of the depth of sleep. Science, 126, 1290-1291.

Lindsley, O. R. (1962). A behavioral measure of television viewing. Journal of Advertising Research, 2, 2-12.

Lindsley, O. R. (1963). Free-operant conditioning and psychotherapy. In Masserman (Ed.), Current psychiatric therapies (pp. 47-56). New York: Grune & Stratton.

Lindsley, O. R., & Conran, P. (1962). Operant behavior during EST: A measure of depth of coma. Diseases of the Nervous System, 23, 407-409.

Lindsley, O. R., Hodika, M. D., & Etsten, B. E. (1961). Operant behavior during anesthesia recovery: A continuous and objective method. Anesthesiology, 22, 937-946.

Lindsley, O. R., & Skinner, B. F. (1954). A method for the experimental analysis of the behavior of psychotic patients. American Psychologist, 9, 419.

Lipsitt, L. P., Peterson, L. J., & Delucia, C. A. (1966). Conjugate reinforcement of operant responding in infants. Psychonomic Science, 4, 67-68.

Logan, F. A. (1960). Incentive: How the conditions of reinforcement affect the performance of rats. New Haven, CT: Yale University Press.

Long, E. R. (1962). Additional techniques for producing multiple-schedule control in children. Journal of the Experimental Analysis of Behavior, 5, 443-455.

Long, E. R., Hammock, J. T., May, F., & Campbell, B. J. (1958). Intermittent reinforcement of operant behavior in children. Journal of the Experimental Analysis of Behavior, 1, 315-350.

Lowe, C. F. (1979). Determinants of human operant behavior. In M. D. Zeiler & P. Harzem (Eds.), Advances in the analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour (pp. 159-192). Chinchester, England: Wiley.

Malagodi, E. F., DeWeese, J., & Johnston, J. M. (1973). Second-order schedules: A comparison of chained, brief-stimulus and tandem procedures. Journal of the Experimental Analysis of Behavior, 20, 447-460.

Margulies, S. (1961). Response durations in operant level, regular reinforcement, and extinction. Journal of the Experimental Analysis of Behavior, 4, 317-321.

Marr, M. J. (1979). Second-order schedules and the generation of unitary response sequences. In M. D. Zeiler & P. Harzem (Eds.), Advances in the analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour (pp. 223-259). Chinchester, England: Wiley.

Matthews, B. A., Shimoff, E., Catania, A. C., & Sagvolden, T. (1977). Uninstructed human responding: Sensitivity to ratio and interval schedules. Journal of the Experimental Analysis of Behavior, 27, 453-467.

Millenson, J. R., Hurwitz, H. M. B., & Nixon, W. L. B. (1961). Influence of reinforcement schedules on response duration. Journal of the Experimental Analysis of Behavior, 4, 243-250.

Morse, W. H. (1966). Intermittent reinforcement. In W. K. Honig (Ed.), Operant behavior: Areas of research and application (pp. 52-108). Englewood Cliffs, NJ: Prentice-Hall.

Notterman, J. M., & Mintz, D. E. (1965). Dynamics of response. New York: Wiley.

Perone, M., Galizio, M., & Baron, A. (1987). Schedule control of human and animal behavior: How different? Experimental Analysis of Human Behavior Bulletin, 5, 24-30.

Perone, M., Galizio, M., & Baron, A. (1988). The relevance of animal-based principles in the laboratory study of human operant conditioning. In G. C. Davey & C. Cullen (Eds.), Human operant conditioning and behavior modification (pp. 59-85). Chinchester, England: Wiley.

Platt, J. R. (1973). Percentile reinforcement: Paradigms for experimental analysis of response shaping. In G. H. Bower (Ed.), The psychology of learning and motivation: Vol. 7. Advances in research and theory (pp. 271-296). New York: Academic Press.

Platt, J. R., (1984). Motivational and response factors in temporal differentiation. In J. Gibbon & L. Allan (Eds.), Annals of the New York Academy of Sciences, 423, 200-210.

Platt, J. R., Kuch, O., & Bitgood, S. C. (1973). Rat's lever press durations as psychophysical judgments of time. Journal of the Experimental Analysis of Behavior, 19, 239-250.

Powell, R. W. (1968). The effect of small sequential changes in fixed-ratio size upon the post-reinforcement pause. Journal of the Experimental Analysis of Behavior, 11, 589-593.

Powell, R. W. (1969). The effect of reinforcement magnitude upon responding under fixed-ratio schedules. Journal of the Experimental Analysis of Behavior, 12, 605-608.

Ramey, C. T., Hieger, L., & Klisz, D. (1972). Synchronous reinforcement of vocal responses in failure to thrive infants. Child Development, 43, 1449-1455.

Reynolds, G. S. (1968). A primer of operant conditioning. Glenview, IL: Scott, Foresman.

Rider, D. P., & Kametani, N. N. (1984). Interreinforcement time, work time, and the post-reinforcement pause. Journal of the Experimental Analysis of Behavior, 42, 305-319.

Rider, D. P., & Kametani, N. N. (1987). Intermittent reinforcement of a continuous response. Journal of the Experimental Analysis of Behavior, 47, 81-95.

Rovee-Collier, C. K., & Capatides, J. B. (1979). Positive behavioral contrast in three-month old infants on multiple conjugate reinforcement schedules. Journal of the Experimental Analysis of Behavior, 32, 15-28.

Rovee-Collier, C. K., & Gekoski, M. J. (1979). The economics of infancy: A review of conjugate reinforcement. In H. W. Reese & L. P. Lipsitt (Eds.), Advances in child development and behavior (Vol. 13, pp. 195-295). New York: Academic Press.

Sanders, R. M. (1969). Concurrent fixed-ratio fixed-interval performances in adult human subjects. Journal of the Experimental Analysis of Behavior, 12, 601-604.

Schaal, D. W., & Branch, M. N. (1988). Responding of pigeons under variable-interval schedules of unsignaled, briefly signaled, and completely signaled delays to reinforcement. Journal of the Experimental Analysis of Behavior, 50, 33-54.

Schaefer, H., & Steinhorst, R. (1959). The effect of changing the schedule upon duration of responding. Journal of the Experimental Analysis of Behavior, 2, 335-341.

Shull, R. L. (1979). The post-reinforcement pause: Some implications for the correlational law of effect. In M. D. Zeiler & P. Harzem (Eds.), Advances in the analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour (pp. 183-221). Chinchester, England: Wiley.

Sidman, M. (1960). Tactics of scientific research. New York: Basic Books.

Sidman, M. (1986). Functional analysis of emergent verbal classes. In T. Thompson & M. D. Zeiler (Eds.), Analysis and integration of behavioral units (pp. 214-245). Hillsdale, NJ: Lawrence Erlbaum Associates.

Skinner, B. F. (1935). The generic nature of the concepts of stimulus and response. The Journal of General Psychology, 12, 40-65.

Skinner, B. F. (1938). The behavior of organisms. New York: Appleton-Century-Crofts.

Skinner, B. F., & Morse, W. H. (1958). Fixed-interval reinforcement of running in a wheel. Journal of the Experimental Analysis of Behavior, 1, 371-379.

Springer, B., Brown, T., & Duncan, P. K. (1981). Current measurement in applied behavior analysis. The Behavior Analyst, 4, 19-31.

Stevenson, J. G., & Clayton, F. L. (1970). A response duration schedule: Effects of training, extinction, and deprivation. Journal of the Experimental Analysis of Behavior, 13, 359-367.

Switzky, H. N., & Haywood, H. C. (1973). Conjugate control of motor activity in mentally retarded persons. American Journal of Mental Deficiency, 77, 567-570.

Thomas, J. R. (1966). Avoidance of a return to the first component of a chain from the terminal component. Journal of the Experimental Analysis of Behavior, 9, 435-441.

Weiner, H. (1962). Some effects of response cost upon human operant behavior. Journal of the Experimental Analysis of Behavior, 5, 201-208.

Weiner, H. (1964a). Response cost and fixed-ratio performance. Journal of the Experimental Analysis of Behavior, 7, 79-81.

Weiner, H. (1964b). Conditioning history and human fixed-interval performance. Journal of the Experimental Analysis of Behavior, 7, 383-385.

Weiner, H. (1969). Controlling human fixed-interval performance. Journal of the Experimental Analysis of Behavior, 12, 349-373.

Weiner, H. (1983). Some thoughts on discrepant human-animal performances under schedules of reinforcement. The Psychological Record, 33, 521-532.

Whaley, D. L., & Malott, R. W. (1971). Elementary principles of behavior. New York: Appleton-Century-Crofts.

Williams. D. C. (1985). Incorporating continuous response and stimulus dimensions into schedule contingencies. Unpublished masters thesis, University of Florida, Gainesville.

Williams, D. C., & Johnston, J. M. (in press). Incorporating continuous response and stimulus dimensional quantities into schedules contingencies. Journal of the Experimental Analysis of Behavior.

Williams, D. R. (1968). The structure of response rate. Journal of the Experimental Analysis of Behavior, 11, 251-258.

Zeiler, M. D. (1977). Schedules of reinforcement: The controlling variables. In W. K. Honig & J. E. R. Staddon (Eds.), Handbook of operant behavior (pp. 201-232). Englewood Cliffs, NJ: Prentice-Hall.

Zeiler, M. D. (1979). Output dynamics. In M. D. Zeiler & P. Harzem (Eds.), Advances in the analysis of behaviour: Vol. 1. Reinforcement and the organization of behaviour (pp. 79-115). Chinchester, England: Wiley.

Zeiler, M. D. (1986). Behavioral units and optimality. In T. Thompson & M. D. Zeiler (eds.) Analysis and integration of behavioral units (pp. 81-116). Hillsdale, NJ: Lawrence Erlbaum Associates.

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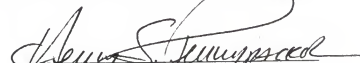

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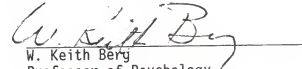

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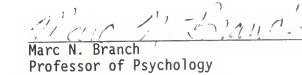

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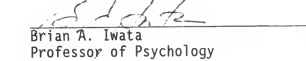

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December, 1989

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